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SUMMARY OF MACH 4 INTEGRAL RAMJET STUDY
During the Period
1 January to 15 July, 1959

Contract 25X1

Project 216

25X1

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THE Marquardt CORPORATION

VAN NUYS, CALIFORNIA

MAC A119B

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I. INTRODUCTION

In 1958, the state of the art of development of materials and ramjet components had reached the stage wherein a high speed (Mach 4) and high altitude (100,000 feet plus) ramjet engine appeared feasible for development and application to long range cruising vehicles. Aerodynamic test data, coupled with engine component data, revealed that long range capabilities increase rapidly with supersonic Mach number as shown in Figure 1 and there is appreciable advantage to pushing cruise speeds as high as material technology will allow.

Studies and component tests made in 1957 and 1958 of an integral cruise type ramjet, as applied to the Super Hustler vehicle, showed that a lightweight ramjet engine could be rapidly developed using existing state of the art knowledge. Consequently, The Marquardt Corporation and the Air Force entered into a program to do further development of engines of this general type which could have application to future ground or air launched cruise vehicles. This study was initiated in January, 1959 and completed with the fabrication of a prototype engine on 15 July, 1959.

II. GENERAL CONCEPTS

A. Applications and Performance

A representative altitude--Mach number operating envelope for such an advanced cruise engine is shown in Figure 2. For air launched missiles or manned aircraft, the initial engine operation could occur at subsonic Mach numbers to supplement booster thrust. At some Mach number between 1.5 and 2.0, depending on the relative size of the vehicle and engine, the ramjet could take over and accelerate the vehicle to cruise conditions. In the case of a supersonic air launch, no supplemental booster system would be required. Another possible application of the engine would be with ground launched vehicles, wherein the engine again would ignite subsonically to augment boost thrust and self-accelerate from the region of Mach 1.5 to 2.0 to cruise Mach number.

The performance capabilities of an integral ramjet engine of this type are shown in Figure 3 which shows acceleration thrust and throttled cruise specific fuel consumption. A minimum cruise specific fuel consumption of 1.86 lbs fuel/lb thrust per hour is obtainable at Mach 4. Tests made in August, 1958 of a full scale engine at the Mach 4 condition demonstrated that such a minimum specific fuel consumption was attainable. The engine was a flight weight type and it incorporated the salient features of the Mach 4 integral cruise type engine. A photograph of this engine is shown in Figure 4.

Table I lists performance variables along a typical trajectory. Appendix A is a preliminary engine model specification with complete engine performance curves presented on a gas generator basis. Component performance levels referred to hereinafter as "estimated values" are those used in arriving at the over-all engine performance presented in the specification.

TABLE I

TYPICAL TRAJECTORY VARIABLES

Time (min)	M_o	Alt. (ft)	A_o (sq ft)	W_a (pps)	T_{t_2} (°F)	P_{t_2} (psia)	P_o (psia)	T_o (°F)	* M_2	$\frac{P_{t_2}}{P_{t_o}}$	F/A	η_c	P_{t_4} (psia)	$\frac{A_5}{A_3}$
ACCELERATION AND CLIMB														
--	2.0	36,500	2.610	112.9	242	15.78	3.2294	-70.0	0.248	0.625	0	Cold flow	13.88	0.400
--	2.0	36,500	2.610	112.9	242	22.82	3.2294	-70.0	0.168	0.904	0.0603	0.90	19.66	0.710
0	2.2	40,000	3.191	128.4	307	26.00	2.7305	-70.0	0.176	0.891	0.0590	0.90	22.31	0.710
0.54	2.4	44,500	3.915	138.6	377	28.13	2.2015	-70.0	0.183	0.874	0.0577	0.90	24.04	0.710
0.84	2.6	48,000	4.510	146.3	454	31.83	1.8620	-70.0	0.179	0.856	0.0562	0.90	27.76	0.648
1.11	2.8	50,000	4.765	151.2	536	38.52	1.6915	-70.0	0.159	0.837	0.0545	0.90	34.92	0.533
1.26	3.0	52,000	5.019	155.1	623	46.30	1.5372	-70.0	0.142	0.816	0.0526	0.90	43.13	0.441
1.50	3.2	55,000	5.296	151.2	715	52.77	1.3319	-70.0	0.126	0.795	0.0507	0.90	50.08	0.369
1.80	3.4	58,100	5.625	147.2	811	59.45	1.1485	-70.0	0.114	0.773	0.0488	0.90	57.12	0.315
2.19	3.6	62,200	5.999	136.6	912	63.33	.94395	-70.0	0.104	0.751	0.0468	0.90	61.40	0.271
2.61	3.8	67,500	6.433	120.1	1018	62.98	.73318	-70.0	0.095	0.728	0.0447	0.90	61.42	0.238
3.00	4.0	71,000	6.657	110.7	1128	68.01	.62017	-70.0	0.084	0.705	0.0425	0.90	66.75	0.201
3.00+	4.0	71,000	7.106	118.1	1128	68.69	.62017	-70.0	0.090	0.712	0.0425	0.90	67.27	0.213
3.06	4.0	75,000	7.106	97.60	1128	56.76	.51245	-70.0	0.090	0.712	0.0418	0.911	55.59	0.212
3.15	4.0	80,000	7.136	77.21	1128	44.77	.40370	-70.0	0.091	0.713	0.0410	0.925	43.83	0.213
3.60	4.0	85,000	7.398	62.77	1144	35.63	.31831	-66.7	0.093	0.718	0.0398	0.940	34.85	0.217
4.32	4.0	90,000	7.719	51.33	1175	28.51	.25204	-57.5	0.095	0.723	0.0385	0.956	27.86	0.222
NOMINAL CRUISE														
	4.0	90,200	7.345	48.38	1176	28.14	.24978	-57.2	0.091	0.717	0.0320	0.961	27.58	0.203

Time (min)	W_f (pps)	** F_6 (lbs)	** F_o (lbs)	$C_{F_{NJ}}$	*** F_{NJ} (lbs)	SFC (lb/hr/lb)	$\frac{W_a}{P_{t_2}}$ $(\frac{in.^2}{sec})$	$\frac{T_E}{P_{t_2}}$ (sq in.)	** F_2 (lbs)	P_2 (psia)	P_4 (psia)
ACCELERATION AND CLIMB											
--	0	3,948	6,798	-.233	-2850	0	7.160	527.0	1,124	15.12	13.35
--	6.676	15,349	6,798	0.6990	8,549	2.811	4.949	864.0	17,298	22.38	17.14
0	7.433	18,683	8,509	0.8130	10,173	2.630	4.940	860.7	20,561	25.44	19.45
0.54	7.837	21,137	10,001	0.9276	11,136	2.531	4.927	857.3	22,942	27.48	20.96
0.84	8.058	23,265	11,445	0.9917	11,819	2.454	4.596	810.0	26,475	31.13	24.90
1.11	8.076	25,075	12,738	0.9825	12,337	2.357	3.926	710.4	32,374	37.84	32.60
1.26	7.994	26,520	13,998	0.9559	12,521	2.298	3.350	617.7	39,206	45.65	41.21
1.50	7.515	27,467	15,060	0.9289	12,406	2.255	2.866	537.4	44,920	52.19	48.55
1.80	7.038	26,415	15,055	0.9037	11,360	2.230	2.476	470.5	50,800	58.91	55.86
2.19	6.265	24,928	14,795	0.8746	10,130	2.226	2.157	413.8	54,274	62.86	60.40
2.61	5.261	23,338	14,401	0.8498	8,936	2.223	1.907	369.0	54,097	62.59	60.66
3.00	4.609	20,775	13,317	0.7939	7,459	2.224	1.627	317.8	58,481	67.68	66.16
3.00+	4.919	22,138	14,215	0.8433	7,923	2.235	1.720	334.5	59,110	68.28	66.60
3.06	3.998	18,242	11,746	0.8367	6,496	2.216	1.720	333.6	48,844	56.42	55.03
3.15	3.102	14,434	9,292	0.8411	5,142	2.172	1.724	334.6	38,530	44.50	43.39
3.60	2.448	11,692	7,595	0.8497	4,097	2.151	1.762	340.3	30,672	35.42	34.49
4.32	1.937	9,508	6,276	0.8464	3,232	2.157	1.800	345.4	24,556	28.34	27.56
NOMINAL CRUISE											
	1.5283	8,596	5,918	0.707	2,678	2.054	1.719	317.5	24,220	27.98	27.36

T_{t_4} = 3190°F

leakage = 0.02
except for nominal
cruise where leakage
= 0.0129

* M_2 based on actual A_2 where $A_2/A_3 = 0.86182$

** $F_1 = P_1 A_1 (1 + \gamma_1 M_1^2) - P_o A_1$

*** $F_{NJ} = C_{F_{NJ}} q_o A_6$

$T_E = P_6 A_6 (1 + \gamma_6 M_6^2)$

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It was originally intended to use a full length variable plug exit nozzle in the engine and the data in Appendix A represent this concept. However, it was decided later in the program to incorporate a blunt plug variable exit nozzle with its attendent advantages of decreased length and weight. For purposes of saving time Addendum II to the preliminary engine model specification (Appendix A to this report) was prepared to reflect the weight, length, and performance estimate changes. The engine, as described in the remainder of this report, incorporates the blunt plug exit nozzle.

B. Components and Materials

A schematic of an engine designed for the envelope of operation of Figure 2 is shown in Figure 5. The major components of the propulsion system are

1. Inlet diffuser
2. Fuel injectors
3. Combustor
4. Exhaust nozzle
5. Fuel pumping and control system and nozzle actuator and control system

1. Inlet Diffuser

Although this component is a very important part of the propulsion system, the diffuser would be part of the airframe itself for an integral engine and is of interest only insofar as its performance affects the engine design. Specifically, the maximum attainable inlet total pressure recovery and mass flow variation with Mach number determines the variation of engine exit nozzle throat size. Secondary considerations are the effect of diffuser outlet velocity profiles on engine performance and control interrelationships between the engine fuel and nozzle geometry controls and the inlet geometry control.

Figure 6 presents a compilation from a literature survey of inlet pressure recoveries for variable geometry inlet configurations tested in the range of Mach numbers of interest. To minimize external drag, an inlet with internal compression is required at Mach numbers as high as 4.0. Complete internal compression type inlets require considerable bleed and bypass flow to give good performance. Consequently, a mixed internal-external compression inlet was considered optimum for this application. It has the following advantages:

1. The diffuser boundary layer bleed for high pressure recovery is small.
2. The variable geometry sections used to obtain high recovery are relatively small as is their motion.
3. The external compression portion yields a variation in mass flow with Mach number that tends to match the engine requirements. A moderate amount of additional bypass at low Mach numbers would also be required for complete matching, however.
4. External drag is very low.

Based upon the data shown in Figure 6, a pressure recovery level was assumed as shown. This level of inlet performance is considered to be consistent with the attainable performance of other major engine components and materials.

2. Fuel Injection System

In order to obtain a maximum number of fuel injection points to facilitate good mixing of fuel and air in a short length, a spray bar system was selected. The engine flow passage is of annular shape, this being dictated by use of the cantilevered plug type variable nozzle. Consequently, the burner itself is annular in shape and there are three circumferential fuel spray bars: one to supply fuel directly into the burner pilot zone, the other two to supply fuel to the outer and inner burner annular passages. These fuel manifolds are referred to as the pilot manifold (center bar) and the main fuel manifolds (outer and inner bars), respectively. Figure 7 is a view of the engine looking downstream showing the spray bars.

3. Combustor

The requirements for high combustion efficiency over a very broad range of burner inlet temperatures, air mass flow, and at fuel-air ratios both lean and rich dictated selection of a can type burner. Development tests of such burners at Marquardt for the RJ59 Mach 3 and Mach 4 engine series under Contract AF 33(600)-22985 provided a wealth of experience and data which not only defined this burner type as the most feasible for this application, but enabled immediate design of a configuration of high performance.

The burner, although annular in shape, is divided circumferentially into three separate sements. These are separated by the longerons which support the center body section and they are placed in the burner section, as shown in the photograph, Figure 7, to minimize engine length and weight.

4. Exhaust Nozzle

To obtain efficient cruise performance at Mach 4, a nozzle of high thrust efficiency is mandatory. An increase in nozzle thrust efficiency of 1 percent results in a reduction in specific fuel consumption of about 5 percent and a resultant range increase of about 5 percent. To obtain the large variation in nozzle throat-to-combustor area ratio required for maximum low speed thrust (71% $A_{throat}/A_{combustor}$) and efficient Mach 4 cruise operation (18% $A_{throat}/A_{combustor}$) a plug type exit nozzle was selected as the most desirable. The plug itself is segmented and very short, as shown previously in Figure 5. The variation in area ratio can be obtained in a short length with high nozzle thrust efficiencies at all area ratios.

5. Fuel and Geometry Control Systems

The center body type engine resulting from the above arrangement of nozzle and combustor provides a convenient location for the fuel and geometry control systems. The actuation unit for the variable exit nozzle is located in the aft portion of the center body and the fuel pumping and control system is located in the forward section. The various elements of these systems and their functions for manned aircraft or missile application are discussed in Section IV of this report.

Fundamentally, the control system keeps the nozzle in the open position and the fuel-air ratio near stoichiometric for high thrust during initial acceleration up to Mach 2.5. From Mach 2.5 to 4, the control system reduces fuel-air ratio and exit nozzle size to maintain high thrust but not over-temperature the engine. At cruise conditions, the fuel-air ratio is reduced further, as is the exit nozzle throat, to maintain optimum cruise specific fuel consumption.

6. Materials

Materials technology had advanced to the stage where not only were adequate materials available to fabricate an engine for extended cruise operation at Mach 4, but a relatively lightweight structure could be developed using these materials. Temperatures which were calculated for different parts of the engine revealed that the nozzle throat area would be the hottest part of the engine required to withstand load and maintain shape. The maximum temperature here would not exceed 1800°F.

The particular materials selected for certain parts of the engine are based upon the maximum operating temperature design life, and, of course, loads. These items are discussed further in Section III.

The materials of particular interest for the engine application are Rene' 41 and Udimet 500, which were planned for use in numerous parts of the engine. These materials, being newer alloys, were not completely documented as to short time tensile and creep data. Consequently, a program was initiated to collect such data using the Marquardt High Temperature Testing machine. The materials investigated were

1. 422M stainless steel
2. 6Al-4V titanium
3. MST821 titanium
4. 16V-2.5 Al-titanium
5. A286 iron base alloy
6. AF71 iron base alloy
7. N-155 mixed base alloy
8. R-235 nickel base alloy
9. L-605 cobalt base alloy
10. M252 nickel base alloy

11. Udimet 500
12. Rene' 41
13. Waspaloy nickel base alloy
14. Commercially pure molybdenum
15. 0.5% Ti-molybdenum alloy
16. Tantalum
17. 0.5% Zr-columbium alloy
18. Tungsten

Figure 8 is a summary of the tensile strength-to-weight ratios at elevated temperatures for several alloys.

In addition, the fabricability characteristics were studied including as radial draw forming, flow turning, impact forming, hydroforming, roll forming, and spinning, as well as fusion, flash, and spot welding.

III. ENGINE DEVELOPMENT PROGRAM

A. Configuration Development

1. Exhaust Nozzle

Small scale nozzle model tests were initiated early in the development program to define the most efficient variable exhaust nozzle configuration. As mentioned previously, a nozzle of high thrust efficiency was mandatory since a small increase in nozzle efficiency is magnified by a factor of about 5 in increased range. Highly efficient nozzles tend to be long, however, and the variable geometry requirement would make a long nozzle very heavy.

A plug type nozzle was selected for this application since high efficiency is obtainable in a relatively short length with a plug type nozzle as compared to a conventional convergent-divergent nozzle. Tests of short length plug nozzles revealed that a high component efficiency could be obtained with a plug nozzle with virtually no physical divergent section downstream from the throat.

A sketch of such a nozzle is shown in Figure 9 together with the over-all nozzle efficiency with secondary flow through the base of the plug. This secondary flow forms an "aerodynamic" taper to the plug which results in high performance with a very short length nozzle. The secondary flow could be diffuser bleed air which has to be discharged overboard, or it could be air taken on board by enlarging the inlet and ducting the air directly through the engine center body from the engine face. The ram drag penalty has been accounted for and the resulting nozzle efficiency shown in Figure 9 is that component efficiency which is applied to the engine gas flow directly.

2. Combustor Designs and Performance

Early tests of a 30-inch diameter plug nozzle type engine in August, 1958 under Contract AF 33(600)-33517 indicated that high combustion efficiency and burner total pressure recovery at the Mach 4 conditions should be relatively simple to achieve. The relatively small exit throat at cruise results in low combustor velocities and low pressure losses. The high inlet temperature (1200°F) is ideal for high combustion efficiency. These early tests revealed that efficiencies above 95 percent were obtainable. Configuration development tests were then concentrated in the low Mach number area (Mach 2.0 to 2.5) where the large exit throat, high combustor velocities, and the low inlet temperature (250°F) made attainment of the target objective of 90 percent combustion efficiency more difficult.

In developing the combustor configuration for the full scale prototype engine, use was made of small scale burner component configuration development tests. Data were obtained utilizing a segment of the full scale burner in the Marquardt Aerothermo Laboratory as well as complete large scale engine testing with a 30-inch diameter engine in the Marquardt Jet Laboratory. Table II lists the test periods, number of runs, variables investigated, etc., for the small scale component development tests. Figure 10 shows typical combustion efficiency test results obtained from the small scale segmental burner tests and Figure 11 illustrates the segmental burner and typical components that were used.

Promising configurations from these tests were integrated into the 30-inch diameter engine design and evaluated. Table III lists the 30-inch engine test periods, runs completed, total burning time, variables, etc. As can be seen, nearly all of the burner tests were performed at the low inlet temperature condition of 250°F.

At the conclusion of the limited engine configuration development test period, a burner configuration was evolved which gave essentially 90 percent combustion efficiency at the low Mach number, low inlet temperatures condition as required. The performance parameter burner drag coefficient (C_{d_b}) was also determined from test results to be of the corresponding proper magnitude of 4.0 at the operating inlet Mach number to the combustor. Figure 12 lists pertinent combustion efficiency results and gives the burner drag performance of the final burner configuration.

Pentane, 80-octane gasoline, JP-4, and RJ-1 fuels were evaluated in developing the burner for the low temperature (250°F) operation. The high temperature RJ-1 fuel is planned for use in the extended cruise mission.

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TABLE II

RESULTS OF SMALL SCALE BURNER CONFIGURATION DEVELOPMENT TEST

Marquardt Aerothermo Laboratory

Phase No.	Test Dates	Number of Runs Completed	Inlet Temperature Range (°F)	Variables Investigated						
				η_c	Fuel-Air Ratio Limit	C_{d_b}	Pilot Fuel Injection	Main Fuel Injection	Burner Geometry	Fuel Effects JP, 80 Octane, RJ-1
I	2-12-59 to 3-5-59 and 3-25-59 to 4-3-59	54	250 to 450	x	x	x	x	x	--	--
II	4-7-59 to 4-15-59	22	250 to 400	x	x	x	x	x	x	x
III	4-29-59 to 5-29-59	18	250 to 400 with A_5/A_3=.65 500 to 1175 with A_5/A_3=.14	x	x	x	x	x	--	x
IV	6-16 and 6-17-59	19	70° to 250°	x	x	--	x	--	x	x

Total number of runs = 113

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TABLE III

RESULTS OF 30-INCH SCALE MODEL ENGINE BURNER DEVELOPMENT TESTS

Marquardt Test No.	Test Dates	Number of Runs Completed	Burning Time (min)	Inlet Temperature Range (°F)	Number of Usable Data Points	Variables Investigated							
						η_c	Fuel-Air Ratio Limit	Ignition	C_{d_b}	Pilot Fuel Injection	Main Fuel Injection	Burner Geometry	Fuel Effects 80 Octane, JP, RJ Fuels
2288 Cell 3	2-13 to 2-27-59	16	18.5	250	99	x	x	x	x	x	x	x	--
2406 Cell 3	3-24 to 3-26-59	3	3.6	250	36	x	--	--	--	x	--	x	--
2425 Cell 3	5-8 to 5-13-59	6	8.5	250 to 427	75	x	x	x	x	x	x	x	x
2290 Cell 8	6-2 to 6-5-59	11	46.7	80 to 300	44	x	x	x		x	x	x	x
Totals		36	77.3		254								

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B. Full Scale Design

Design of a flight prototype engine was completed during the contract work period of January to July, 1959. Fabrication of a prototype engine consisting of flight engine components wherever possible was also completed.

Studies made during the RJ59 engine programs revealed that ramjet engines delivered more thrust and better specific fuel consumption per pound of engine weight as engine diameter increases. The RJ59 series was developed in 36-inch engine size, since this was considered to be the largest practical engine diameter consistent with test facility limitations. Facilities considered were primarily the Arnold Engineering Development Center, Ordnance Aerophysics Laboratory, and the Marquardt Jet Laboratory. The combustor flow area of the RJ59 series was approximately 1000 sq in. and the integral cruise type engine is designed with the same flow area, which is a measure of required air flow rates, and, hence, facility requirements.

1. Flight Design

A sketch of the resulting design of the flight type engine is shown in Figure 13. The engine consists of several subassemblies exclusive of the fuel and geometry control packages, which are discussed in Section IV. The forward outer shell is the main structural subassembly and it would transmit axial loads to the airframe at the forward ring which is designed to attach to the airframe with a V-type clamp. The main structural ring would transmit normal maneuver loads to the airframe at three points through rollers. This whole structural assembly is exposed solely to inlet air temperatures and receives no heat from the combustion section.

The longeron--center body assembly transmits all nozzle plug forces and inertia loads from the center body with enclosed fuel and geometry control package to the outer structural assembly. The longerons, three in number, separate the annular burner into three segments and the longerons receive little or no heat from the combustion region.

The variable plug assembly is of leaf or "iris" type design. As shown in Figure 13, the aft portion, which is leafed, rotates about hinges and it changes the effective throat area of the exhaust nozzle between 18 and 71 percent of the combustor flow area.

The outer combustor and nozzle assembly is simply skinned material primarily carrying bursting loads. The cooling liners shown duct fuel free inlet air aft to the nozzle entrance on the outside shell as well as the center body. These liners are louvered in such a manner that some of the air inside escapes and film cools the liner itself. The remainder exits at the liner end and film cools the center plug and outer nozzle assemblies.

The maximum steady state operating temperatures of the major parts forming these subassemblies are shown in Figure 14. These temperatures were determined for a representative trajectory wherein the engine accelerates from Mach 2 to 4 at maximum power, climbs to cruise altitude, and operates for 1 to 3 hours at cruise power settings. Figure 8 summarized the performance of the various materials at elevated temperatures. The material selections resulting on the basis of these temperatures, loads, etc., are shown in Figure 15. Much use is made of Rene' 41, which appears to be optimum for many of the parts considering manufacturability as well as material performance. Adequate creep or "life" data for the more attractive material are not yet available and ultimate analysis may reveal one of the materials other than Rene' 41 more suitable.

Utilizing the estimated operating temperatures, material properties, load factors, etc., to select optimum materials and shapes, a resulting engine weight of 880 lbs is estimated. This weight breakdown is shown in Table IV.

2. Prototype Engine

For early structural and aerothermodynamic development testing, a prototype engine was fabricated which was of flight engine design wherever possible. A photograph of this engine is shown in Figure 16. The engine was complete except in two respects, namely it had no control package since long lead times are required for designing and making numerous castings, and it had no variable exit plug for the same reasons. Two plugs were fabricated simulating the variable plug in the maximum power position and in the cruise power position. In addition, N-155 alloy was substituted for other materials in some areas, again due to long lead time requirements for the correct materials.

The engine was completely instrumented and ready for test at the end of the contract work period.

IV. CONTROLS

The fuel and control system for the Mach 4 integral cruise engine was designed to provide optimized control functions for the complete propulsion system which included the variable geometry air induction system and the ramjet engine.

This section summarizes the concepts and design principles of the over-all power control system.

The control system design presented in the subsequent discussions was conceived to be fundamentally suitable to both piloted and nonpiloted vehicle applications. All control functions are completely automated and only the mode of propulsion system operation as required for specific missions or trajectories is selected by either manual or further automated means. The piloted application is used as the primary reference in these discussions.

TABLE IV

ESTIMATED WEIGHT BREAKDOWN FOR THE
MACH 4 INTEGRAL CRUISE TYPE RAMJET

(Incorporating Blunt Plug Exit Nozzle)

Component	Sheet Metal	Ring & Mach. Parts	Castings	Purchased Parts	Totals
Fwd. inner body	16.10	20.10	--	--	36.20
Aft inner body	28.50	22.40	--	--	50.90
Fwd. inner body liner	7.75	--	--	--	7.75
Aft inner body liner	24.65	--	--	--	24.65
Longeron assembly	42.50	--	6.00	--	48.50
Fuel delivery	11.70	--	11.80	--	23.50
Burner	93.4	5.9	--	--	99.30
Fwd. liner outer	22.00	--	--	--	22.00
Aft liner outer	45.5	--	--	--	45.50
Diffuser assembly	37.3	59.40	--	--	96.70
Tailpipe	89.5	--	--	4.0	93.50
Exit plug	38.00	27.00	44.00	10.0	119.00
Miscellaneous fasteners	--	--	--	9.0	9.00
Miscellaneous	--	--	--	15.0	15.00
Package including actuators & ignition system	--	--	--	--	188.50
Total					880.00 lbs

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The design of an engine bleed air turbine powered unit for hydraulic and electrical accessory power is also presented.

A. System Functions

Figure 17 indicates the type of propulsion system (with major input and output variables affecting control design) for which the subject control system is designed.

The general requirements performed by the power control system can be summarized as follows:

1. Induction System Controls

   a. Position inlet geometry and engine bypass duct for minimum drag during engine nonoperating phases.

   b. Position inlet geometry to provide optimum pressure recovery and capture area at low supersonic speeds.

   c. Position inlet geometry in such a manner that external compression shock waves are held in stable locations and so that maximum pressure recovery is available to the engine.

   d. Provide starting capabilities of the propulsion system anywhere within the flight envelope and restarting capabilities in the event of diffuser shock expulsion.

   e. Regulate engine bypass duct flow to provide proper matching of inlet and engine air mass flow characteristics.

2. Engine Controls

   a. Regulate ignition and reignition fuel flows.

   b. Control desired modes of fuel distribution to the combustor.

   c. Limit exhaust gas temperatures during accelerating thrust conditions at all Mach numbers.

   d. Limit exhaust gas temperatures during emergency thrust operation.

   e. Optimize acceleration and cruise specific fuel consumptions through control of pressure recovery, fuel flows, and exit nozzle size.

Further specific required functions and design considerations for the power control system are reviewed separately.

Precision operation was specifically designed for the flight ranges of Mach 2 to 4 at 30,000 to 100,000 feet altitude. The degree of precision outside of this nominal envelope was not specifically examined.

B. System Concept

The inlet controls and engine controls are, by function, conveniently separated into two subsystems. The basic function of the inlet and controls is to provide the optimized inlet capture area and ram pressure recovery potential. The engine controls (in this case regulation of engine bypass duct air, heat addition, and exit nozzle area) then are charged with maintaining maximum potential pressure recovery while delivering acceleration and cruise thrusts at minimum specific fuel consumption.

Even though the inlet and engine controls are not integrated through common loops, they of course must act synergistically during operations such as ignition, possible diffuser shock expulsion, etc. Therefore, the inlet control system was designed to function independently and to compliment engine controls in cases where normal propulsion system operation need be established or re-established.

The engine control system involves the regulation of three variables: bypass air, fuel flow, and exit nozzle area. The basic criteria require a system arrangement which assures maximum thrust potential for acceleration at low or ram-jet takeover Mach numbers and accurate optimization of specific fuel consumption during the high Mach number cruise operation. Consideration of the sensitivity of engine characteristics to possible controlled variables (See Figure 18) and physical limitations of both engine and control determined the arrangement of control functions and loops as shown in Figure 19 in order to best satisfy performance accuracy requirements.

The system concept reflected by the control system design (Figures 19 and 20) provides for closed loop control of functions such as exit nozzle area, bypass air flow, and inlet geometry, whereas engine fuel flow is controlled by an open loop system. This type of arrangement is indicated by relative sensitivity of engine performance to the controllable variables and also by the difficulty in determining effective areas of variable geometry engine components such as the exit nozzle under conditions of thermal expansion, thermal creep, exhaust gas leakages, change coefficients, etc. Closed loop controllers automatically compensate for these variations.

Conversely, the open loop function of the engine control system (fuel-air ratio regulation) can be independent of engine and induction system performance deviations. Therefore, the fuel flow control loop can conveniently accept external commands for selecting thrust levels and start up and shut down sequencing.

C. System Design

1. Inlet Geometry Control System

By selection of proper pneumatic pressure parameters available from external and internal compression fields of the induction system, a closed loop control system which maintains a fixed pressure ratio was made possible instead of a more complicated open loop scheduling system which would schedule inlet position with Mach number. The suitability of the parameter (a fixed ratio of external diffuser pressure to throat pressure) is shown in Figure 21 wherein the command geometry is positioned in such a manner that ideal performance is closely matched over the design Mach number range.

The inlet geometry control system is shown in Figure 22. The system consists of hydraulic (3000 psi) and pneumatic (ram pressure) components. The oil--hydraulic power source was used because of the significant heat transfer problems under the 1200°F environment involved in supplying power from the remotely located engine. Hydraulic power from the air turbine motor unit would be used.

The control and actuator system consists of a proportional plus integral pneumatic control unit which senses the signal pressure ratio. The output pneumatic signal is received by a pneumatic signal booster unit which provides a position output and drives the actuator hydraulic servo through mechanical linkages. The resultant actuator motion and position is fed back mechanically to the signal booster-servo valve linkage, thus making it a proportional element. This arrangement avoids a double integrating system (controller plus servo valve actuator) while still maintaining the zero steady state error characteristic of the proportional plus integral system.

Full extended or retracted actuator positions (minimum or maximum induction inlet areas) can be commanded by means of separate bias to the signal booster unit of the system.

2. Engine Air Bypass Control System

The engine air bypass system functions only to match diffuser and engine air flow characteristics (See Figure 31). Except for low Mach number operation wherein bypass may be required even though the engine were controlled to consumed maximum possible air flow, the need for bypassing air is dependent upon the type and accuracy of control of the engine operating variables. Therefore, control of bypass air is integrated with the engine control system. This control means is discussed within the engine control section of this report.

However, due to the remote location of the bypass system from the engine proper, the bypass controls are not physically integrated with the engine control system and they also receive actuator power from a vehicle hydraulic power source (air turbine motor unit) rather than from engine accessory units.

The bypass control system, as shown in Figure 23 is composed of components of the same design as those for the inlet geometry control system except for variation in sizing, gains, and calibration characteristics.

3. Engine Fuel Control System

The fuel flow control system (Figure 24) is designed to operate with several distinct modes of control. A simplified representation indicating the various loops and modes of control is shown in Figures 25 and 26. Figure 25 represents a manual input arrangement for selecting the desired mode of operation whereas Figure 26 shows the resulting control performance with input variations. The fuel delivery characteristics of Figure 26 are fixed irrespective of flight Mach number, altitude, or day temperature.

Briefly, in reference to Figures 25 and 26, the control system modulates fuel-air ratio directly during ignition procedures and minimum thrust demand conditions in order to match engine combustor characteristics at lean burning operation. Intermediate and maximum power operation (and emergency power) are governed by the control system so that combustion chamber temperature is maintained at the prescribed calibrations irrespective of ram air temperature (altitude, Mach number, and ambient air temperature). The third control loop is required during long cruise durations wherein one of the two fuel injector rings is made inoperative (for added combustor structural life) and a high gain (thrust versus speed) characteristic is provided by the control for convenient speed regulation. This high gain thrust control again controls combustion temperatures on an open loop basis, but, due to the narrow band, high gain characteristics, maximum temperature limits are maintained by a fuel-air ratio override loop. Accuracies determined for the engine control system are described in Figure 27.

The fuel controllers are of pneumatic, hydraulic, and mechanical design which are packaged and housed within the ramjet engine center body (See Figure 33). The controls require no external power source for operation because they utilize ram air and fuel as working fluids for computator and actuator power. (The exceptions which use external power sources are intermittent electrical power requirements for combustor spark ignition, and in the case of manual selection of operational modes, inputs through a mechanical shaft are required.)

For convenience, the fuel flow and control system can be discussed in terms of four subsystems. These include: the pneumatic computing system, the fuel metering and injector system, the power mode selector system, and the fuel pumping system.

The heart of the pneumatic computing system is the engine air mass flow computer. It operates by sampling engine air flow at the engine inlet (downstream from the diffuser bleeds and engine air bypass ducting). A fixed percentage of engine air is captured by the sampling probes. A pressure signal which is proportional to sampled air (and therefore engine air flow) is obtained through manipulation of the sampled air, by fuel-to-air heat exchangers, prior to exhausting through calibrated choked nozzles. Experimental performance of the air mass flow computer component is presented in Figure 28.

The intelligence provided by the engine air mass flow computer provides a fundamental reference from which all fuel flow functions may be related to engine operation. Accurate fuel-air ratio regulation to the primary injectors for ignition, combustor zone stabilization, minimum fuel-air ratio limits, and to both primary and secondary injectors for maximum fuel air limits are readily achieved.

Fuel-air ratios are varied by automatic and manual means to attain acceleration maximum thrust schedules and to select desired thrust levels for cruise, deceleration, and emergency power conditions by processes which bias the basic air mass flow signal pressure. The signal is, in general, modulated by a series of pneumatic pressure divider units, each of which delivers a separate output pressure which is a function of the air mass flow computer signal and the manual or automatic demand input to the variable pressure dividers.

The automatic inputs, with reference to the system schematic of Figure 24, are governed by stagnation air temperature sensers. One temperature senser operates a pressure divider unit so that the output signal varies engine acceleration fuel-air ratios so as to maintain a constant combustion chamber temperature for all Mach numbers and elevated thrust demands as illustrated in Figure 26. A second temperature senser, used only during cruise speed operation, biases the control signal in order to vary engine thrust inversely with vehicle speed and therefore provide vehicle speed stabilization (See Figure 29).

The mode selector system consists of a complex of switching valves which port the desired pneumatic signals to the fuel metering valves and also includes variable pneumatic pressure divider units which receive commands for adjusting fuel-air ratio and intermediate engine thrust levels. All pneumatic switches and pressure dividers are synchronized to operate from a single rotary input shaft. An interlocked push-pull mechanical input is provided for selecting the cruise operating mode of control operation.

Engine bleed air powers the turbine driven centrifugal fuel pump which raises fuel pressures from tank pressure at the engine inlet to that required to operate the fuel controls, actuators, and fuel injection system. The turbine air power is controlled by throttling the bleed air upstream from the stators so that the pump head rise does not exceed the requirements of the system.

Control of the pump serves three additional objectives. First, it reduces system pressures to a minimum, which allows use of lightweight magnesium fuel component castings under the extreme temperature environments (up to 500°F fuel temperatures). Second, the throttling of turbine supply air in this manner reduces engine bleed air at cruise speeds and gives an incremental improvement in specific fuel consumption. It also makes practical the adoption of a small high pressure pump run directly by the turbine pump shaft, since the pump control limits maximum shaft speeds to slightly over 20,000 rpm. This small, high pressure pump supplies hydraulic power to the engine exit nozzle actuator system. The compatability of turbopump characteristics with systems requirements is demonstrated in Figure 30.

A portion (approximately 25 percent) of the engine pump fuel output is recirculated to an ejector at the pump inlet which significantly increases the suction specific speed to allow minimum fuel tank pressurization.

The two fuel metering valves are of nearly identical design and differ only in internal port sizing as required capacities differ slightly. As previously indicated, they are arranged in parallel and they independently meter fuel to the primary and secondary injector systems. Simple orifice type fuel nozzles are installed in both primary and secondary injectors. However, the primary injector, because of its larger flow range requirements, incorporates pressure sensitive switching valves between two sets of nozzles so that maximum system pressures are minimized. The more mechanically complicated, spring loaded, variable area type fuel nozzles were not deemed practical since, under certain engine operating conditions, the injectors encounter 1200°F environments without benefit of fuel flow cooling.

The fuel metering valves are the flow regulating type (volumetric) which deliver a scheduled fuel flow characteristic in accordance with the input pneumatic differential signal. A constant fuel pressure drop is maintained across the variable area metering orifice by a servo controlled throttling valve. The metering orifice area is governed by a positioning servo loop which is in turn positioned by a spring loaded diaphragm which receive the pneumatic demand signal. The control is fuel temperature compensated. Therefore, the unit regulates the fuel weight rate flow for any specific fuel.

4. Variable Exit Nozzle Control System

The exit nozzle throat area is controlled to maintain approximately 97 percent of diffuser critical pressure recovery within limitations of full nozzle area excursion. As previously indicated, the engine air bypass system and the exit nozzle system (Figures 23 and 24) are complimentary toward maintaining critical diffuser pressure recovery under certain conditions. During low Mach number operation, at intermediate and high power levels, engine bypass control is required even with full open nozzle as shown in Figure 31. Second, the high response critical control circuit is placed in the bypass system in order to minimize actuator size and power to the more massive and higher loaded exit nozzle. Both the exit nozzle and bypass control systems operate from the same diffuser probe pressures which describe critical pressure recoveries. However, the two systems are calibrated with an incremental difference so that the bypass system is not activated except during conditions wherein the exit nozzle is incapable of maintaining critical recoveries. By these means, engine thrust and specific fuel consumption are optimized except during brief transient periods (Note Figure 31).

The exit nozzle control is also relied upon to set engine aerodynamic flow conditions within specified limits required for ignition at all altitudes and Mach numbers. These burner conditions are satisfied by adjusting the exit nozzle in such a manner that approximately 65 percent of critical pressure recovery is maintained under nonburning operation. This setting also assures supercritical diffuser operation during the transition from cold flow to burning operation. The exit nozzle area control for ignition is regulated through the normal control system which is biased to maintain the lower pressure recovery setting. Nominal exit nozzle positioning for maximum power and ignition scheduling is shown in Figure 32.

The exit nozzle controller is an integrating type control with velocity feedback. The controller unit consists of diaphragm motors which receive the pressure recovery pneumatic signals and the velocity feedback signal. The integrating diaphragm reuses the diffuser demand signals, one of which passes through a restrictor thus providing the integral characteristic. The controller is stabilized by the second diaphragm which receives an exit nozzle position signal from a pneumatic variable pressure divider and ports the signal across the diaphragm through a restrictor to provide an opposing force during transients. The diaphragm motor system actuates the two-stage hydraulic servo valve to govern exit nozzle actuator motion.

Fuel is used as the hydraulic working fluid for the controller and piston type nozzle actuator. A high pressure hydraulic source (1500 psi) is provided by the small (3 gpm) positive displacement pump which is directly driven by the air-turbine-driven main fuel pump shaft.

D. Environmental Considerations

All fuel system and exit nozzle control system components are integrated into one package assembly which is installed within the engine center body. The system layout (Figure 33) illustrates the installation of the system. The entire assembly is fuel cooled by the metered fuel flows and by the turbopump bypass flow to the pump supply ejector. In addition, molded thermal insulation is applied to external surfaces.

These cooling techniques make possible the use of magnesium castings for most control housings under conditions of 1200°F ambient environment when supplied with fuel at 500°F. Components such as the turbo pump inlet ducting and the exit nozzle actuator, which are subject to convection and direct radiation from combustion chamber and exit nozzle walls, are fabricated from high temperature steels. Special laminated high temperature spacers are used at the package tie-down points to minimize heat conduction.

Addition of heat to internal control parts through flowing ram air signal lines is avoided since all air is cooled by the fuel-to-air heat exchanger which also provides the computing function in the air mass flow computer circuit.

Conversely, heat conduction effects from the package body to the bimetallic temperature sensers were minimized by locating the sensers at the extreme forward end of the package, ahead of the steel fuel injector manifolding in the package assembly, remote from the magnesium fuel cooled control sections.

The suitability of this approach toward achieving environmental resistance was exhibited experimentally by subjecting pneumatic computers (with diaphragm motors) and fuel flow regulators, in a packaged assembly, to the maximum environmental temperatures and heat transfer rates. The fuel metering valves and cooling passages of the magnesium castings were supplied with fuel at near maximum temperatures. Control performance and structural integrity were satisfactory after steady state temperature distribution was achieved and maintained as shown in Figure 34. A photograph of the environmental test stand and the engine model (control test cell) is shown in Figure 35.

Nonmetallic elements such as diaphragm motors and seals were further evaluated experimentally in order to select the most reliable materials and fabricating techniques for the required temperature operating range. Figure 36 describes the environmental life of the selected diaphragm material, which was DuPont Fairprene elastomer on glass fabric. The manufacturing process was noted to be the most significant factor in achieving satisfactory performance and life at high temperatures for a given combination of materials.

E. Installation and Ground Check Features

The complete engine control, pump, and nozzle actuator assembly is installed and removed through the center plug of the variable area exit nozzle. The package tie-down point is located at the forward end of the exit nozzle where steel supports, cast integrally with the exit nozzle actuator (See Figure 33) are bolted to an engine structural ring. Forward package shear support is provided between the forward steel fuel manifolding casting of the package assembly and the forward engine inner body structural ring.

The leading edge of the inner body aerodynamic shape is incorporated into the package design in order that fuel lines to the injector nozzles could be attached to the package through slip joint seals. Thus, package installation and removal is facilitated and connections remain sound under environmental temperatures where axial differential expansion between the package and engine inner body occurs.

All electrical lines, fuel supply lines, manual control input shafts, external pneumatic signal lines and ground check lines are carried from the engine attach pad through a single engine longeron to the inner body and control package. Consequently, the control system installation is performed by attaching lines at two points (fuel injector lines at the engine face and all other connections at the engine attach pad) and bolting the assembly in place through the exit nozzle at the aft engine structural ring.

Provisions are made to ground check the operation of the fuel control and pumping system and the exit nozzle actuator system while the engine is installed on a vehicle. All necessary connections and lines (additional to normal flight connections) including auxiliary fuel control discharge ports, pneumatic signal inputs, a turbo pump ground check air supply line, and a pneumatic control circuit vacuum line are provided at the engine attach pad. A quantitative check of the package performance may be conveniently conducted by use of these provisions for ground supplied hydraulic and pneumatic services.

F. Air Turbine Motor Accessory Drive

Accessory hydraulic and electrical power is provided through use of an air turbine motor drive unit as the prime mover. Propulsion system diffuser bleed air (See Figure 17) is ducted to the turbine motor unit. The unit is designed to deliver full power requirements for the propulsion system and a vehicle. Design horsepower outputs are a maximum of 54 horsepower for continuous operation and 29 horsepower during average conditions.

The unit (and air ducting) consists of an upstream air inlet throttling valve (and associated speed and overspeed controls), a single stage turbine, hydraulic lubricating and scavenging pumps, hydraulic recirculating pump for the alternator cooling system, a gear box and the two output power pads for the alternator and hydraulic pump. The air turbine motor system is shown schematically in Figure 37.

1. Inlet Power Control Valves

The inlet air valving is basically the turbine inlet duct. The duct contains two valves capable of throttling bleed air flow to the turbine. The forward valve is an on-off valve used for normal start and shut down functions as commanded by a signal to the electrical actuators. In addition, it receives an electrical signal from the overspeed governor to command emergency shutdown.

The aft valve is positioned by a hydraulic actuator to regulate air bleed power to maintain constant turbine speed under transient and steady state conditions of accessory power demand and available bleed air pressure ratios and mass flows from the engine.

2. Turbine Assembly

The turbine is an axial flow, single stage, reaction type unit. The turbine operates with 100 percent admission with the speed controlled (32,000 rpm) by the inlet duct valve which varies the available air horsepower. Materials for the disk and blade are forged Rene' 41 and investment cast 713C alloy, respectively. Choice of these materials made design possible for safe operation at 130 percent overspeed at maximum temperature (1270°F) and yet control possible failure within a narrow band of overspeed values at all operating temperatures. Since failure would occur at the blade roots, all parts can be contained within the exhaust duct section in the event of failure. The turbine shaft is mounted in a ball and roller combination.

3. Speed Controls

Design speed is maintained (to an accuracy of ±1 percent) with a fly ball type hydraulic governor driven by the turbine. The speed governor positions the hydraulic actuator on the inlet air valve to control the turbine input ram air power.

A mechanical fly ball governor is mounted on the turbine shaft which actuates the shutoff air valve through a mechanical linkage in the event of overspeed. The spring loaded governor initiates valve closing at 110 percent overspeed and the valve is full closed at 120 percent overspeed.

4. Gear Box

Power from the unit is provided at the output pads for the alternator and hydraulic pump mounting, each turning at 8000 rpm. Speed reduction to the output pads is accomplished from a single reduction spur gearing with the turbine shaft pinion and the output shaft drive gear. A secondary accessory pinion on the turbine shaft mates with a gear which mounts on the shaft which drives the speed control governor at 6000 rpm. The governor drive shaft has a pinion that mates with two additional gears for driving the two lubricator oil cooling pump arrays at 6000 rpm.

5. Lubricating and Cooling Systems

The lubricating and cooling systems (Shown in Figure 37) consist of the turbine and gear box lubricating system, a generator cooling system, and an oil cooling system. All system components, such as supply and scavenge pumps, filters, oil sumps and relief valves, are integral with the air turbine motor design as indicated in Figure 38. The aft half of the gear case includes pads to mount pumps, governors filter, etc. Oil lines are based in it to eliminate external plumbing, and the hot and cold sumps are cast on the front of the turbine housing.

The lubrication and cooling system for the turbine shaft and bearings is designed to provide for operation under the severe thermal environmental conditions of 300°F ambient temperature, -65°F to 300°F oil supply temperature, and 1270°F turbine air supply temperature. Lubrication and cooling is accomplished by pumping the oil (Specification MIL-L-7808C) through a nozzle jetting in to the end of the turbine shaft. Centrifugal force aids in discharging the oil to three different locations. The first two are small lubricating jets discharging horizontally to the bearings. The third is for cooling purposes. The oil flow (approximately 2 gpm) absorbs heat travelling through the shaft toward the front bearing. It is then discharged from the shaft forward of the front bearing through holes drilled in a high thermal conductivity copper disk holding carbon nozzle seals. The oil flow returns through the turbine housing around the outside of the bearing, thus cooling the bearing internally and externally.

G. Development Status

Completion status of the inlet control system, engine fuel and control system, and the air turbine motor unit at the termination of this study is tabulated below.

Phase	Inlet Control System	Engine Fuel & Control System	Air Turbine Motor Unit
a. System concept and design approach	95%	98%	90%
b. System and component detail design analysis	90%	95%	80%
c. System and component detail design and release	50%	50%	40%
d. Heat transfer analysis	50%	50%	60%
e. Materials and stress analysis	80%	85%	85%
f. Component and element testing	5%	8%	0%
g. Systems testing	0%	3%	9%
h. Manufacturing investigation and tool engineering	98%	98%	90%

V. CONCLUSIONS

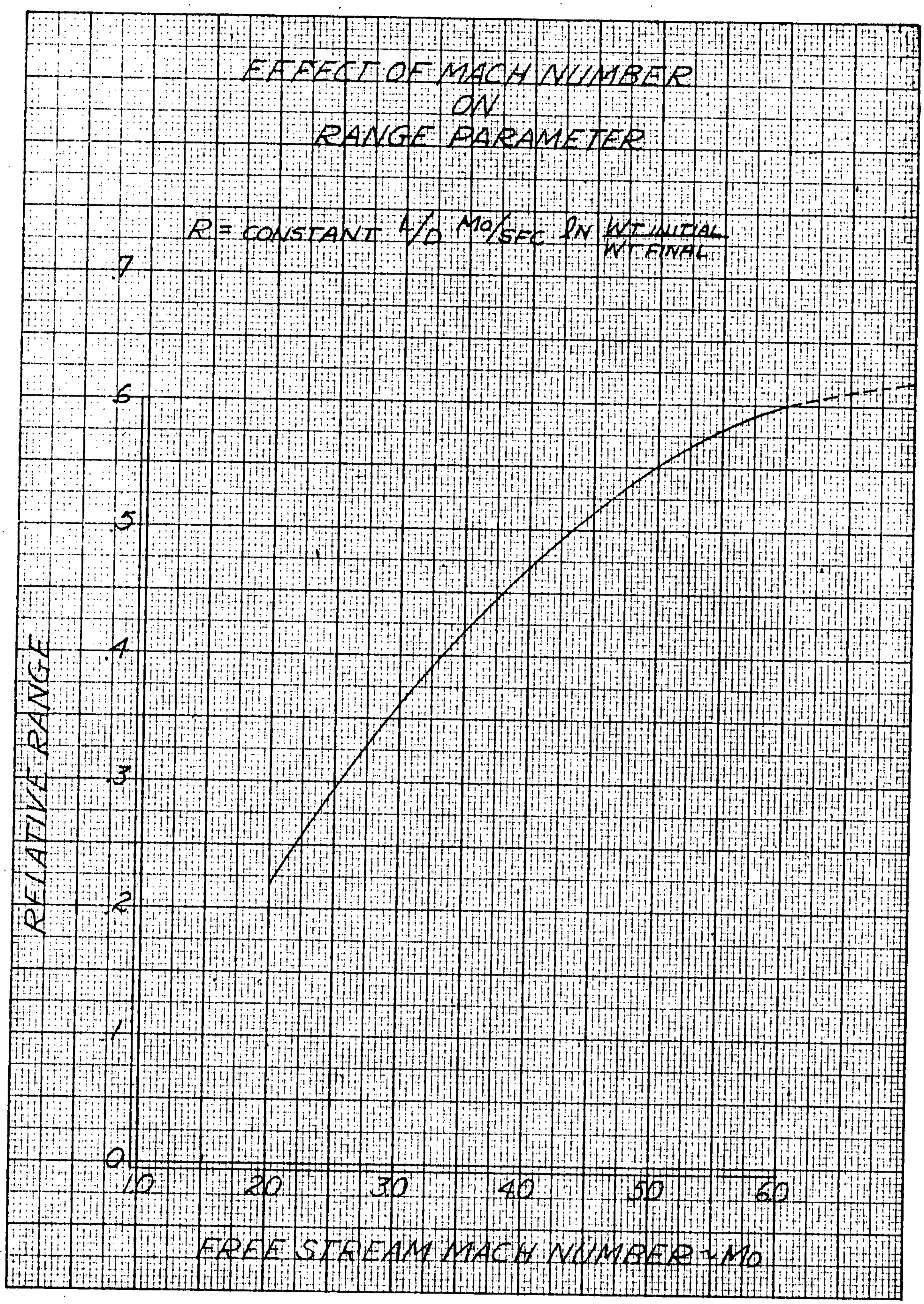
As a result of the six-months study of the Mach 4 integral cruise engine, it has been concluded that

1. A combustion system can be developed which can be spark ignited and which will give combustion efficiencies up to 90 percent during near stoichiometric operation during climb and acceleration and 95 percent during Mach 4 cruising at lean fuel-air ratios at altitudes on the order of 90,000 feet.

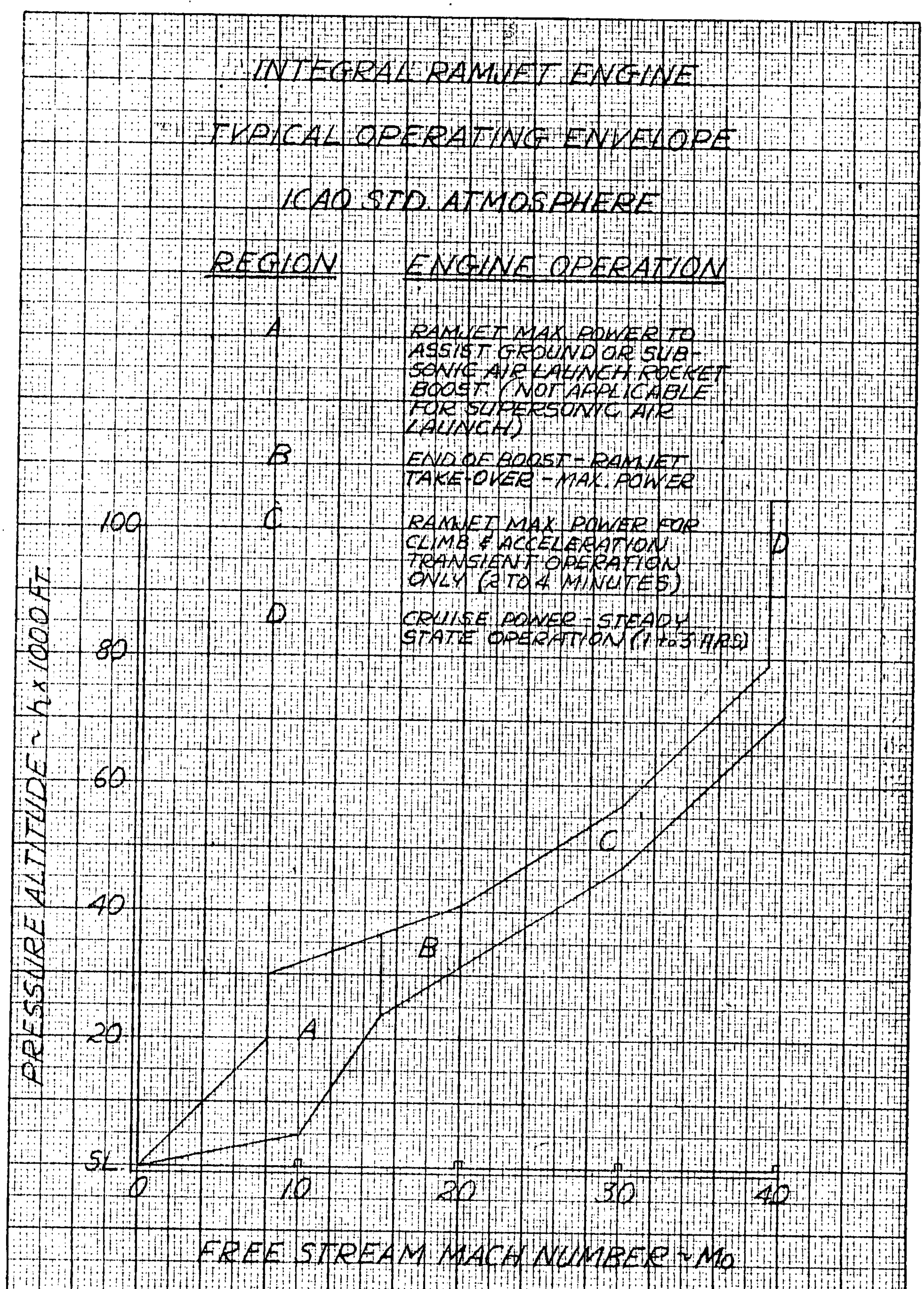
2. A lightweight ramjet engine structure, made largely of Rene' 41 alloy, can be fabricated and should withstand the environments imposed during long periods of cruising operation at Mach 4 (incorporating an overlapping leaf, variable plug exit nozzle).

3. An engine fuel pumping and power control system can be built largely from modified XRJ43-MA-9 (Bomarc B) components which will provide necessary fuel pressurization and power control during long periods of cruising operation.

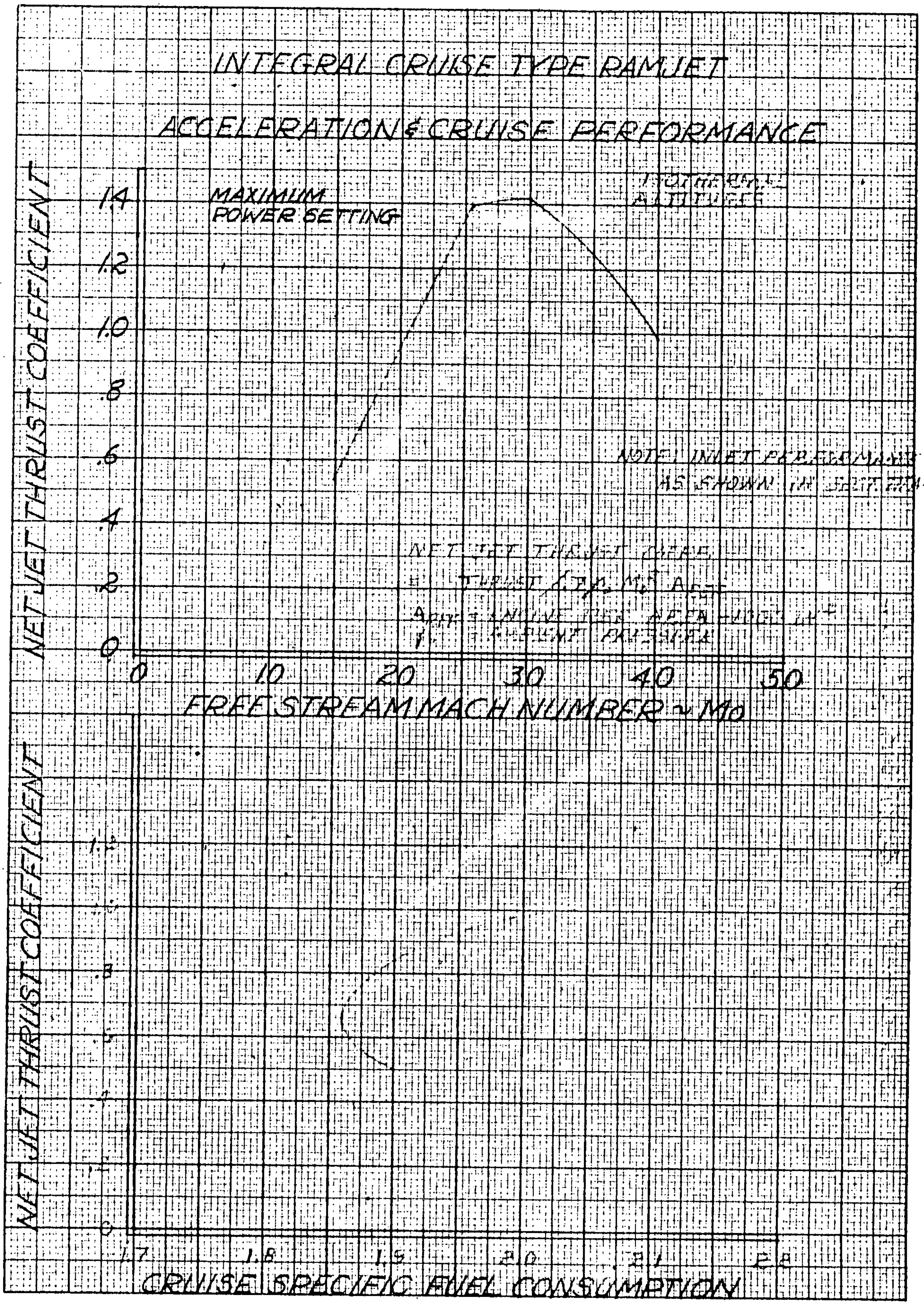
4. Stated more generally, it is concluded that the Mach 4 integral cruise ramjet engine state of the art has been sufficiently well established to be used as a foundation for immediate development of flight equipment.


EFFECT OF MACH NUMBER
ON
RANGE PARAMETER
R = CONSTANT L/D Mo/SFC ln WT INITIAL/WT FINAL
RELATIVE RANGE
0
1
2
3
4
5
6
7
10
20
30
40
50
60
FREE STREAM MACH NUMBER ~ Mo

MAC A673


INTEGRAL RAMJET ENGINE
TYPICAL OPERATING ENVELOPE
ICAO STD. ATMOSPHERE
REGION
ENGINE OPERATION
A
RAMJET MAX. POWER TO ASSIST GROUND OR SUB-SONIC AIR LAUNCH ROCKET BOOST. (NOT APPLICABLE FOR SUPERSONIC AIR LAUNCH)
B
END OF BOOST - RAMJET TAKE-OVER - MAX. POWER
C
RAMJET MAX. POWER FOR CLIMB & ACCELERATION TRANSIENT OPERATION ONLY (2 TO 4 MINUTES)
D
CRUISE POWER - STEADY STATE OPERATION (1 to 3 HRS)
100
80
60
40
20
SL
0
1.0
2.0
3.0
4.0
A
B
C
D
PRESSURE ALTITUDE ~ h x 1000 ft
FREE STREAM MACH NUMBER ~ Mo

MAC A673


INTEGRAL CRUISE TYPE RAMJET
ACCELERATION & CRUISE PERFORMANCE
MAXIMUM POWER SETTING
NET JET THRUST COEFFICIENT
1.4
1.2
1.0
.8
.6
.4
.2
0
0
1.0
2.0
3.0
4.0
5.0
FREE STREAM MACH NUMBER ~ Mo
NET JET THRUST COEFFICIENT
CRUISE SPECIFIC FUEL CONSUMPTION

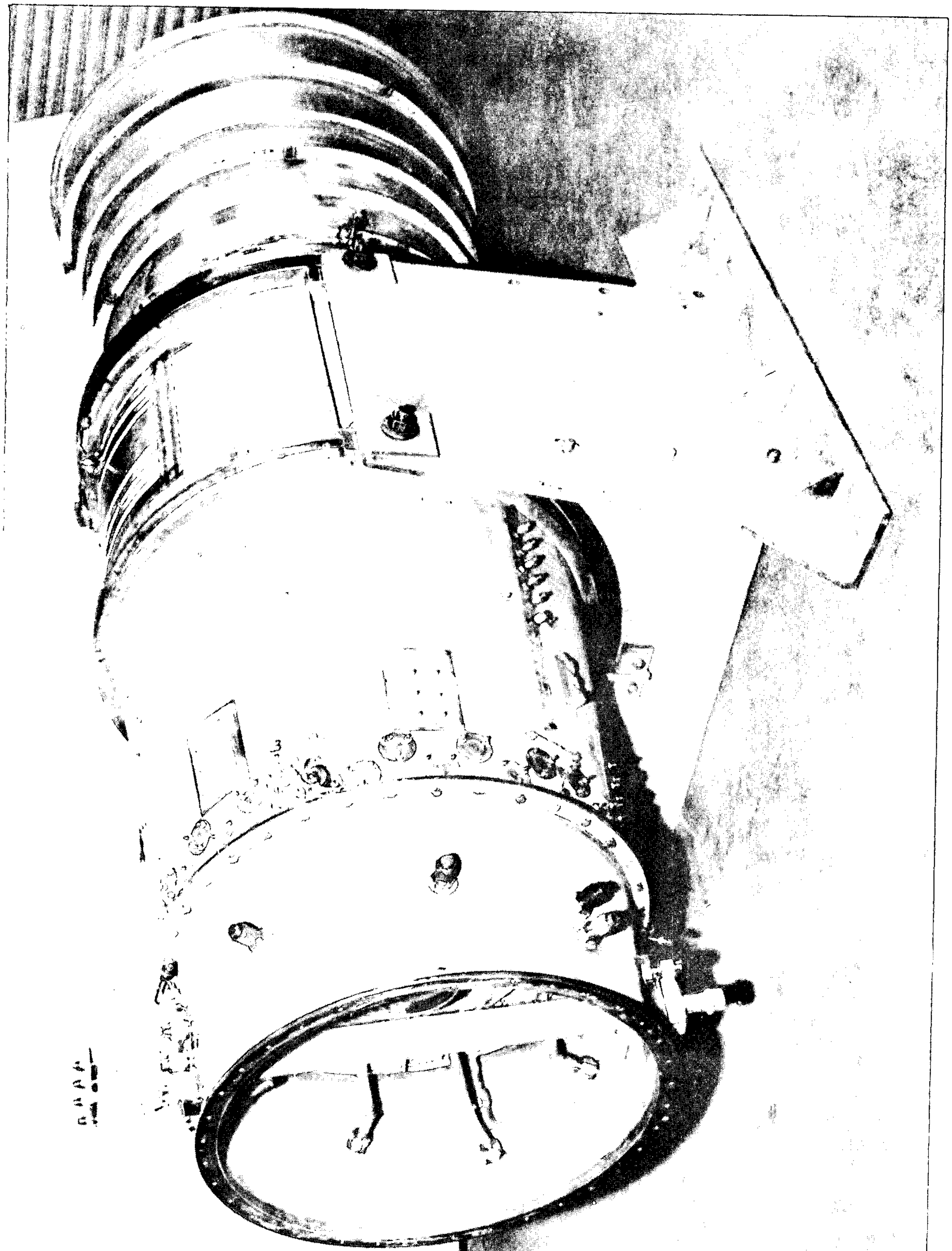
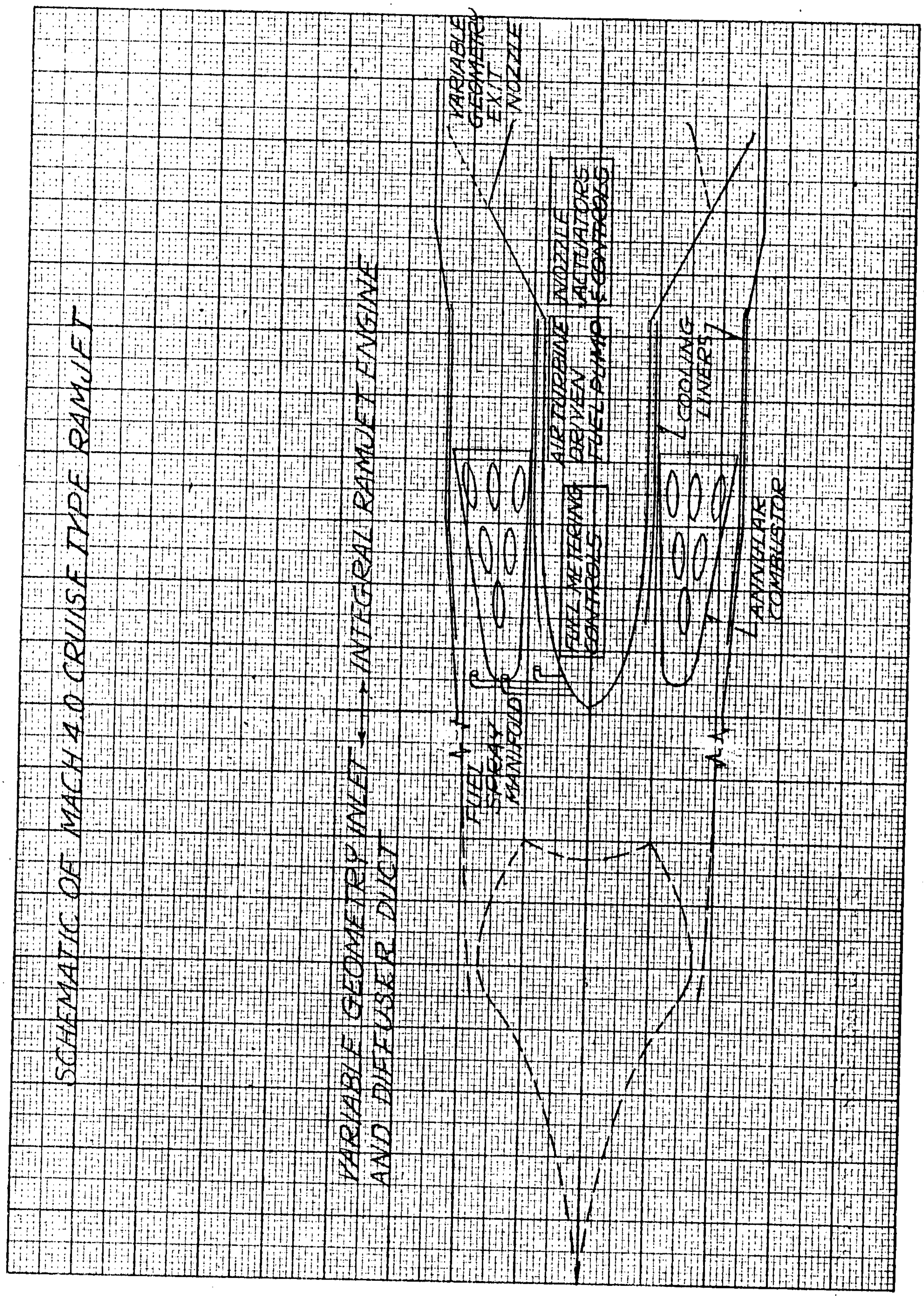
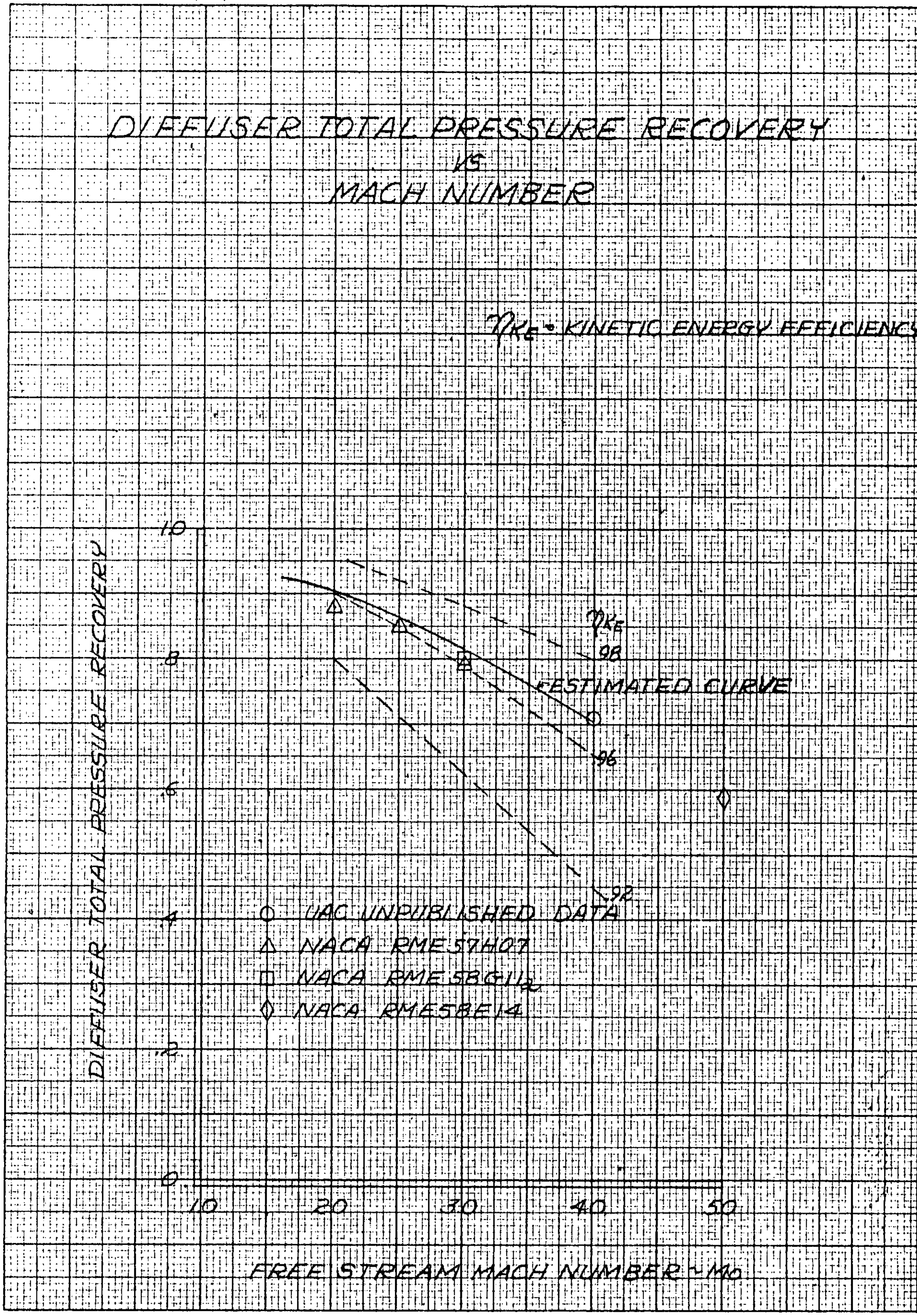


FIGURE 4 - Mach 4, 30-inch Diameter Structural Test Engine, Side View


SCHEMATIC OF MACH 4.0 CRUISE TYPE RAMJET
VARIABLE GEOMETRY INLET AND DIFFUSER DUCT
INTEGRAL RAMJET ENGINE
VARIABLE GEOMETRY EXIT NOZZLE
NOZZLE ACTUATORS & CONTROLS
AIR TURBINE DRIVEN FUEL PUMP
FUEL METERING CONTROLS
COOLING LINERS
ANNULAR COMBUSTOR
FUEL SPRAY MANIFOLD


DIFFUSER TOTAL PRESSURE RECOVERY
VS
MACH NUMBER
η_{KE} = KINETIC ENERGY EFFICIENCY
η_{KE}
.98
.96
.92
ESTIMATED CURVE
UAC UNPUBLISHED DATA
NACA RME57H07
NACA RME58G11a
NACA RME58E14
DIFFUSER TOTAL PRESSURE RECOVERY
1.0
.8
.6
.4
.2
0
1.0
2.0
3.0
4.0
5.0
FREE STREAM MACH NUMBER ~ Mo

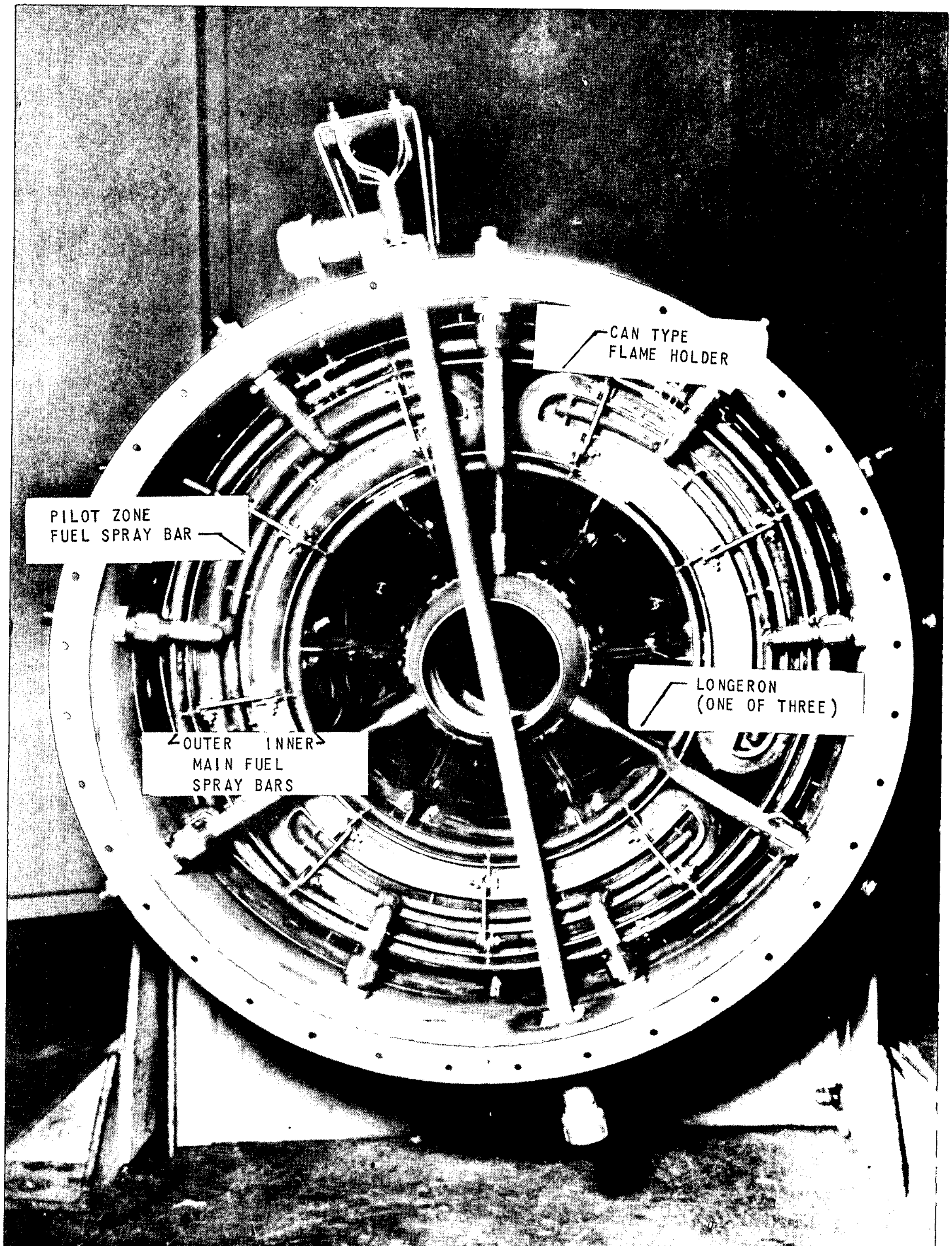
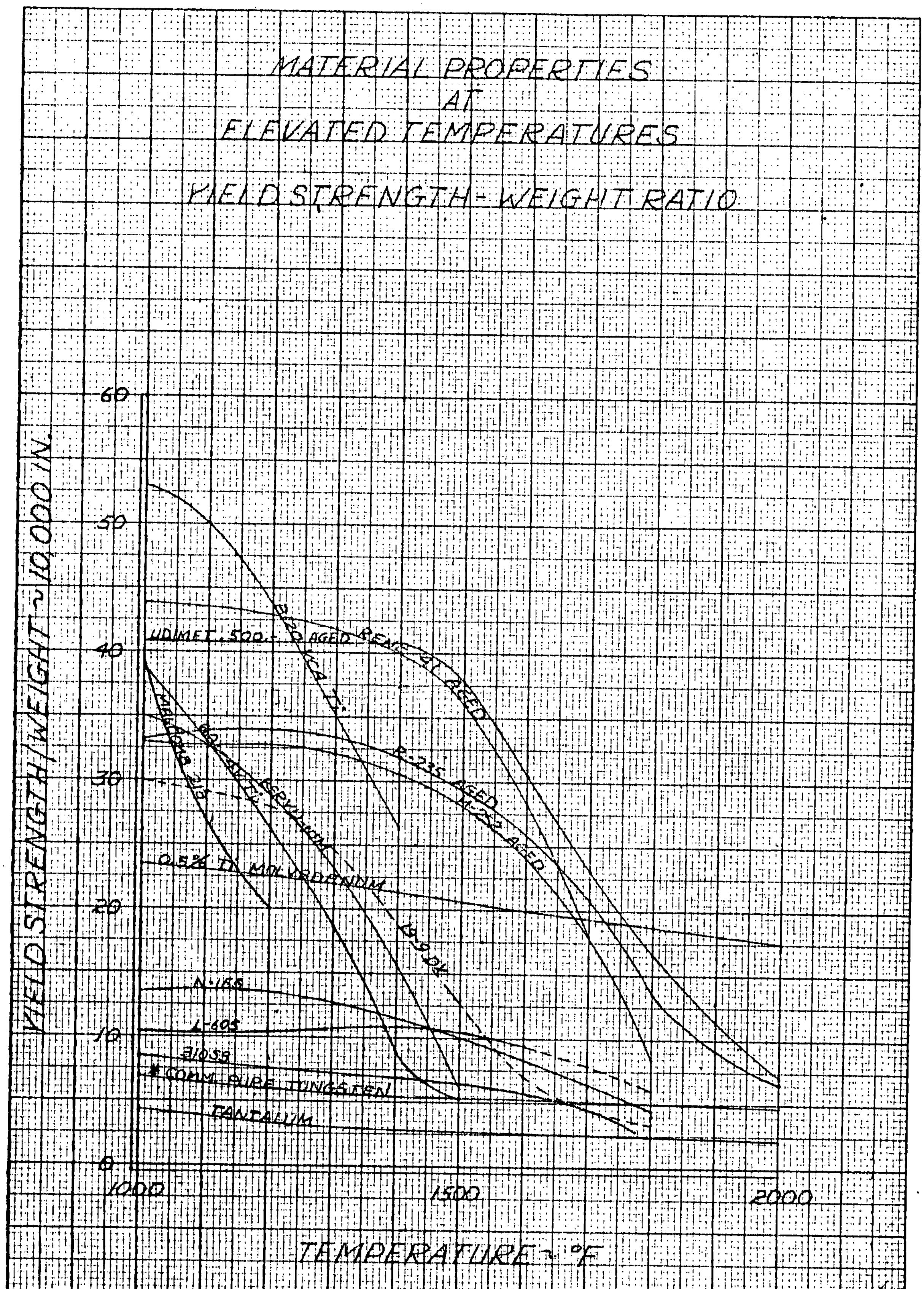
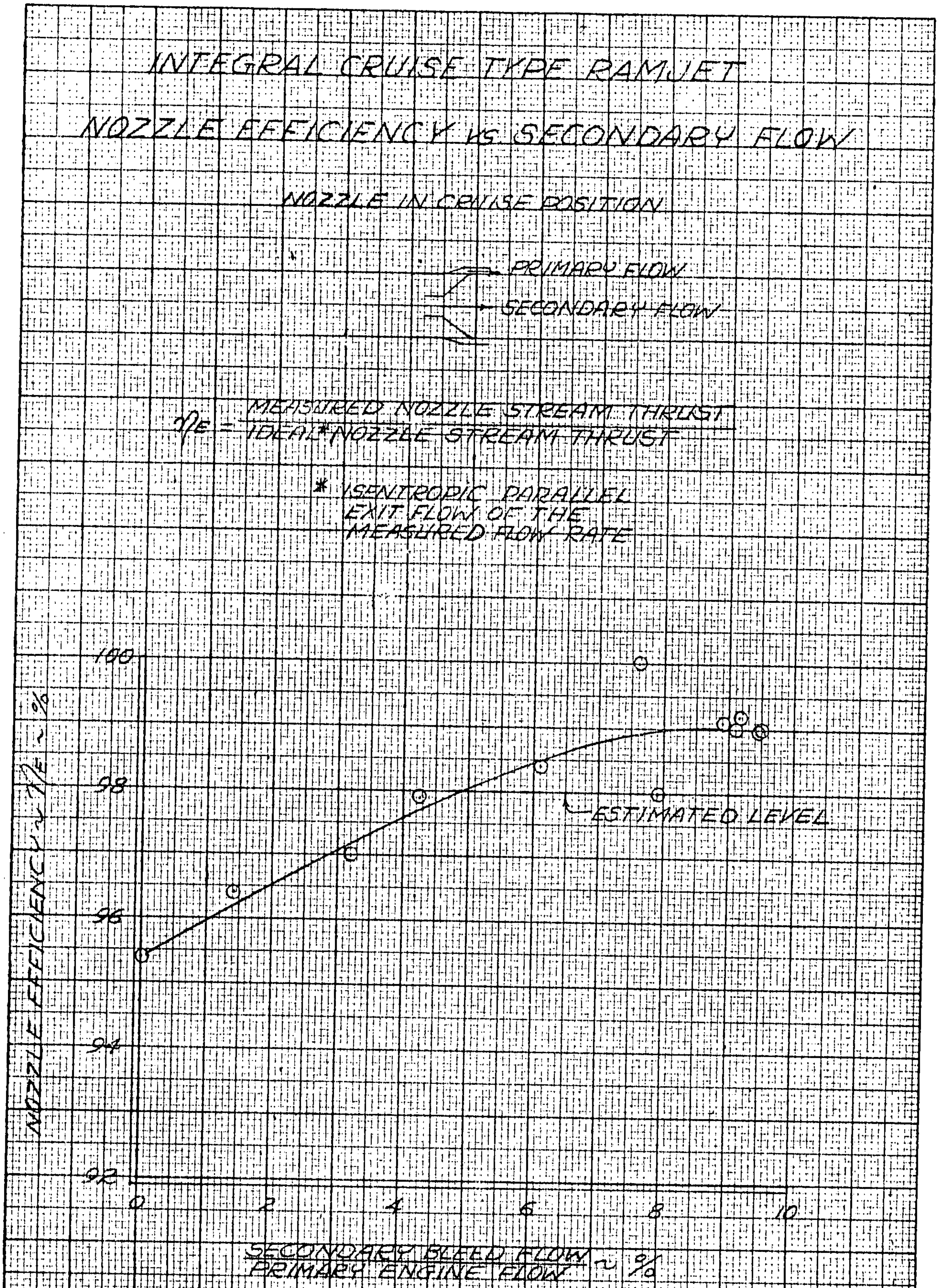


FIGURE 7 - Mach 4, 30-inch Structural Test Engine, Looking Aft

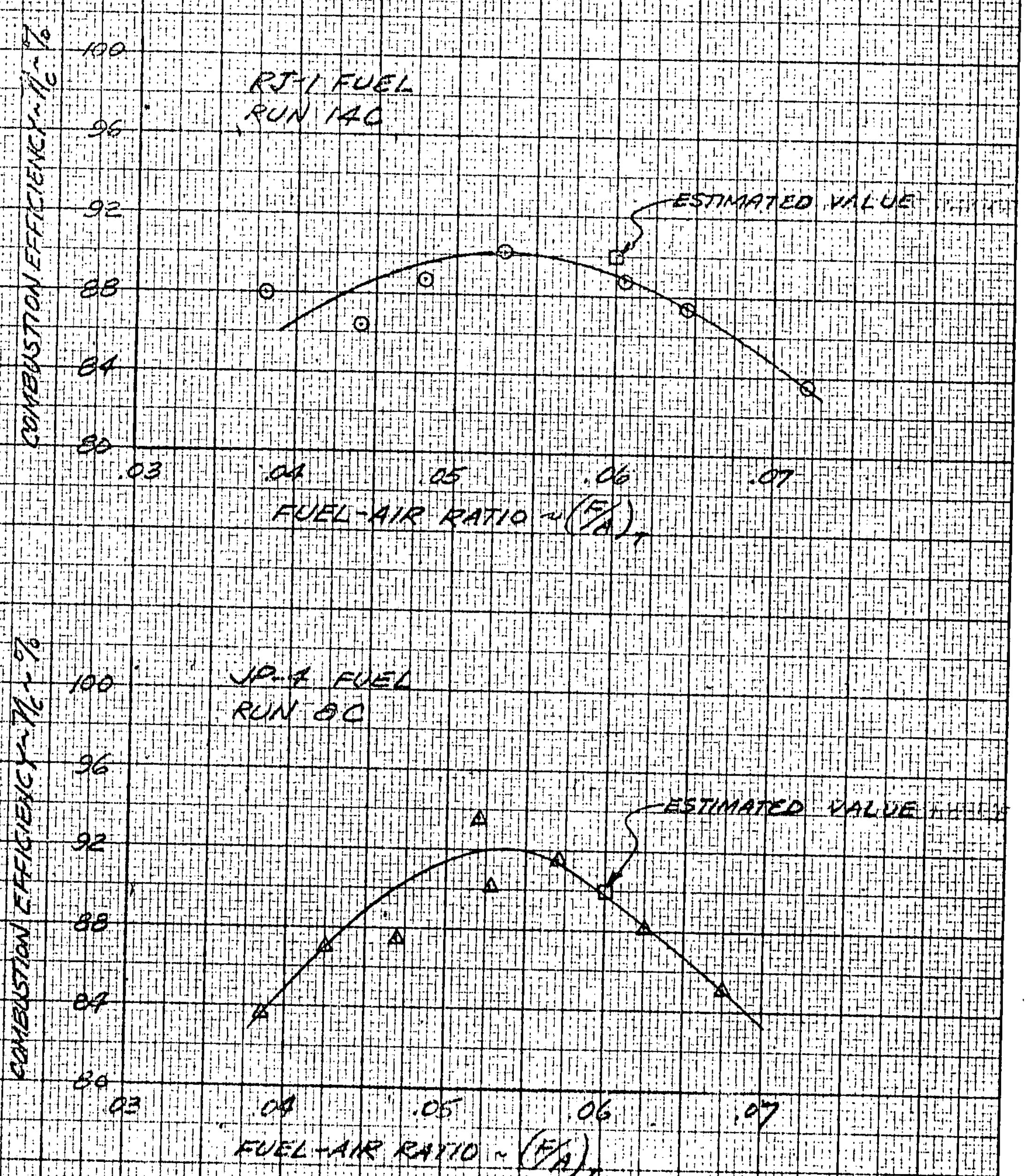

MATERIAL PROPERTIES
AT
ELEVATED TEMPERATURES
YIELD STRENGTH - WEIGHT RATIO
YIELD STRENGTH/WEIGHT ~ 10,000 IN.
TEMPERATURE ~ °F
UDIMET 500 - AGED
REX 41 AGED
B-235 AGED
0.5% TI MOLYBDENUM
19-9 DL
N-155
L-605
S1035
COMM. PURE TUNGSTEN
TANTALUM
60
50
40
30
20
10
0
1000
1500
2000

MAC A673


INTEGRAL CRUISE TYPE RAMJET
NOZZLE EFFICIENCY vs SECONDARY FLOW
NOZZLE IN CRUISE POSITION
PRIMARY FLOW
SECONDARY FLOW
$\eta_E = \frac{\text{MEASURED NOZZLE STREAM THRUST}}{\text{IDEAL* NOZZLE STREAM THRUST}}$
* ISENTROPIC PARALLEL EXIT FLOW OF THE MEASURED FLOW RATE
100
98
96
94
92
0
2
4
6
8
10
ESTIMATED LEVEL
NOZZLE EFFICIENCY ~ η_E ~ %
$\frac{\text{SECONDARY BLEED FLOW}}{\text{PRIMARY ENGINE FLOW}}$ ~ %

SEGMENTAL BURNER TESTS
COMBUSTION EFFICIENCY EVALUATION

$M_0 = 2.0$
ALTITUDE = 30,000 FT.



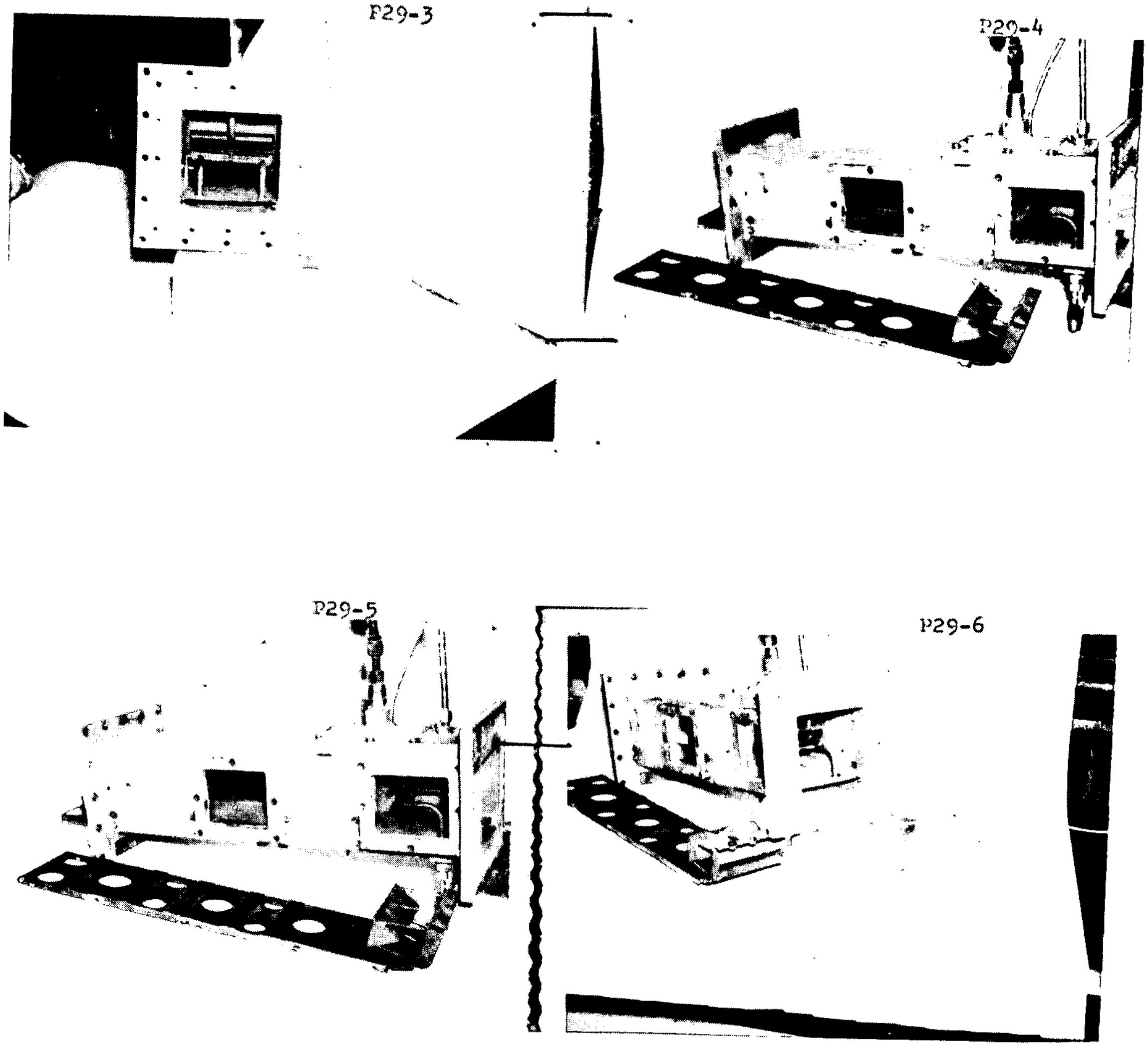
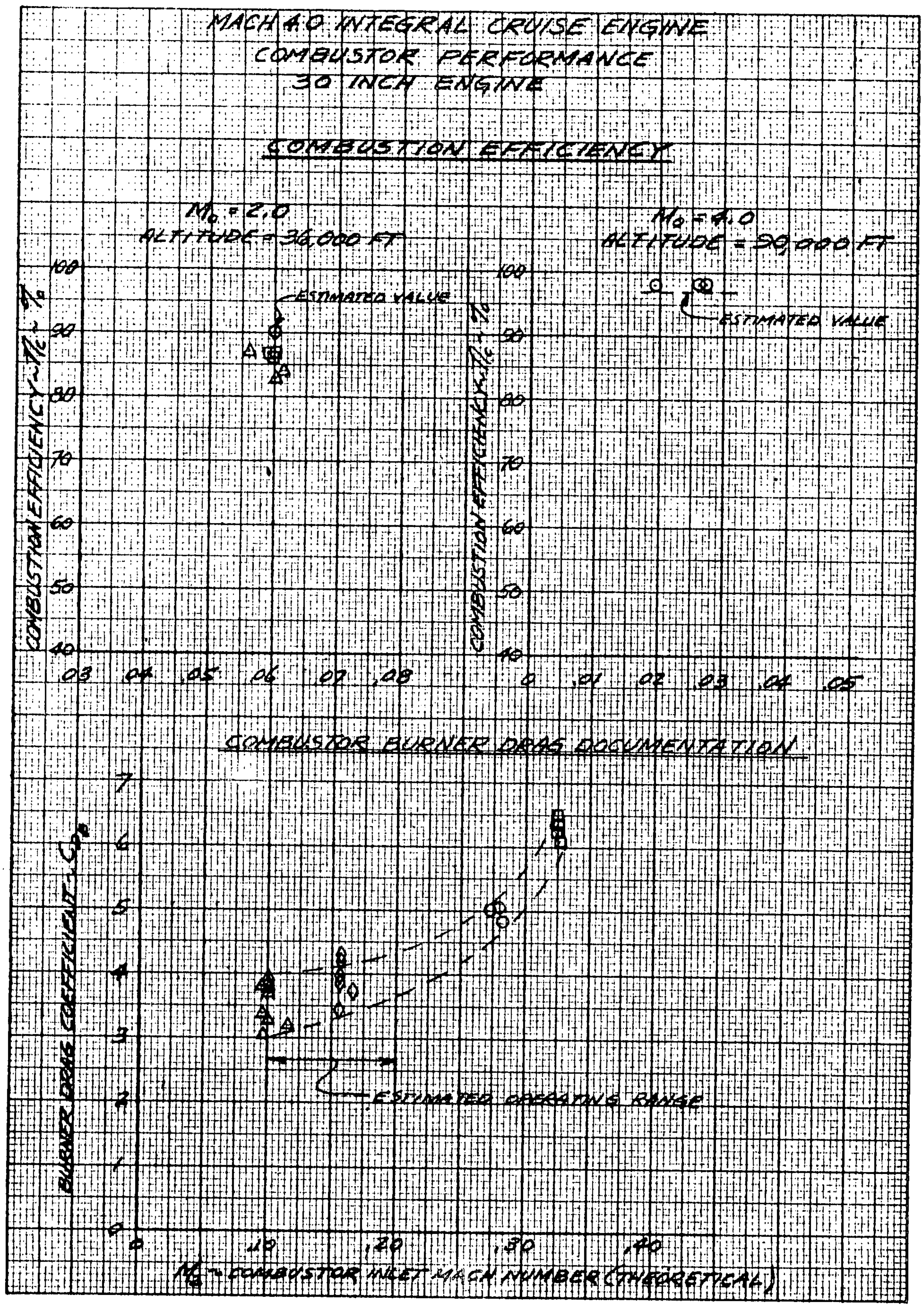
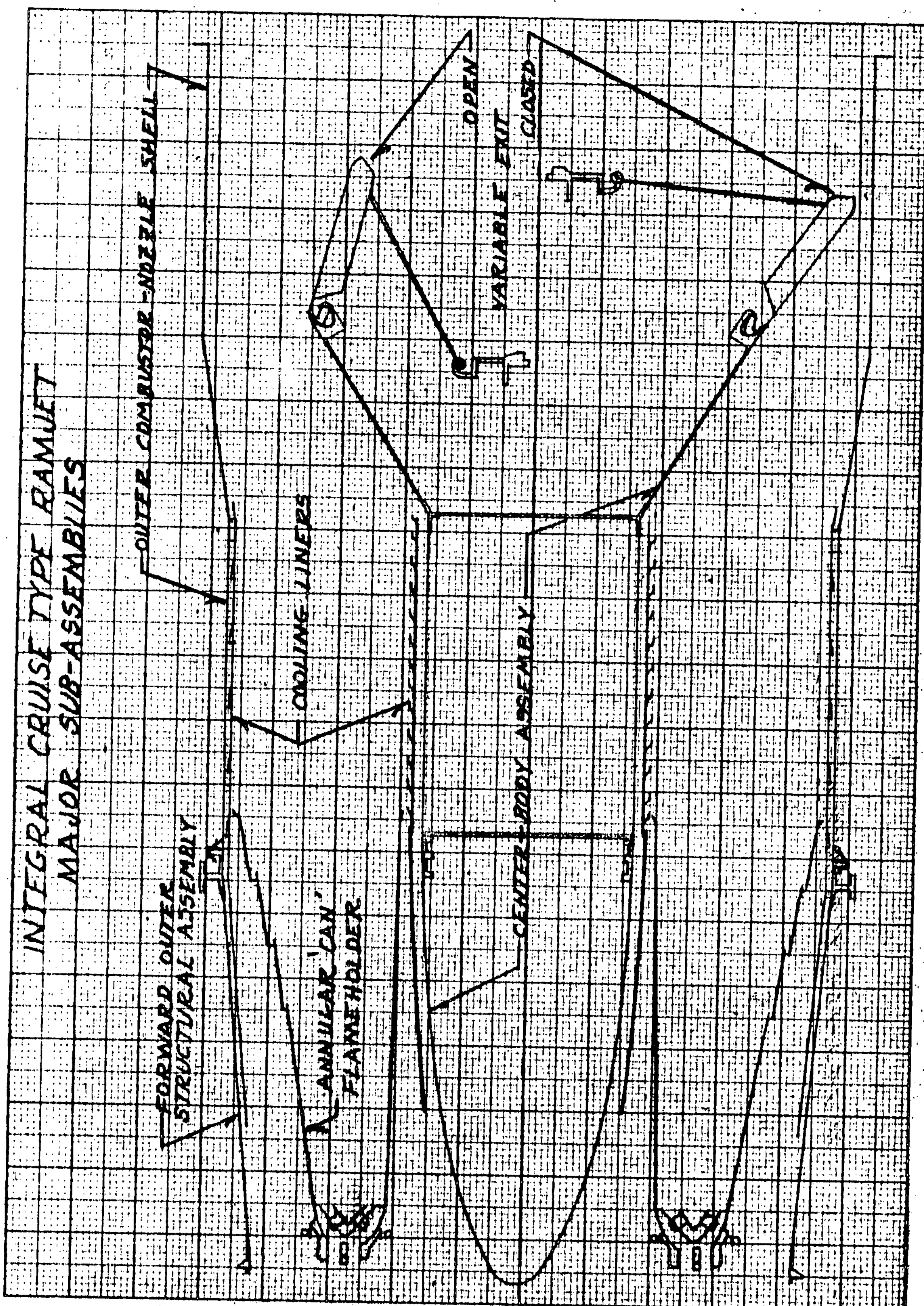


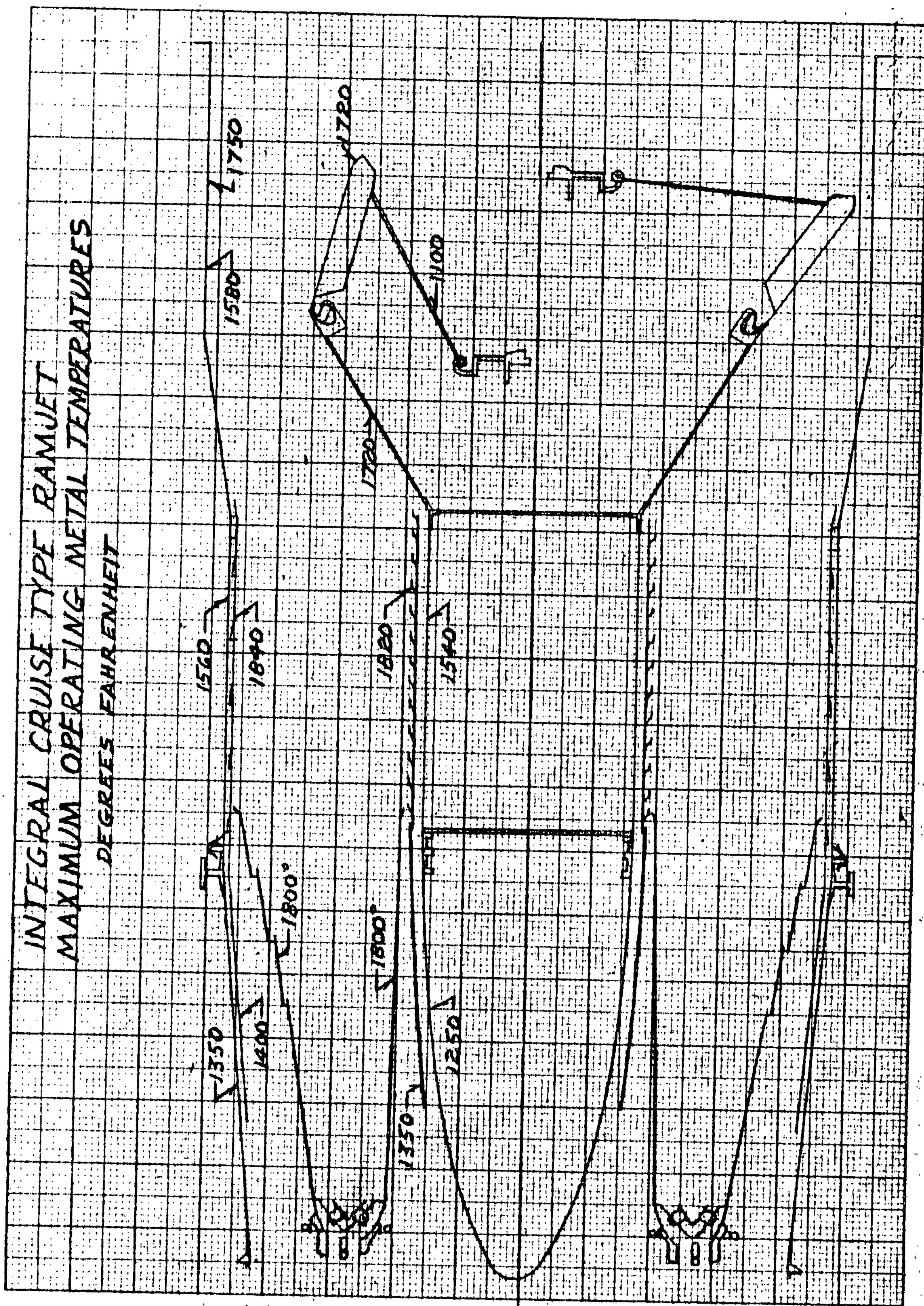
FIGURE 11 - Segmental Burner and Components

Declassified in Part - Sanitized Copy Approved for Release 2012/08/13 : CIA-RDP89B00487R000400740011-9

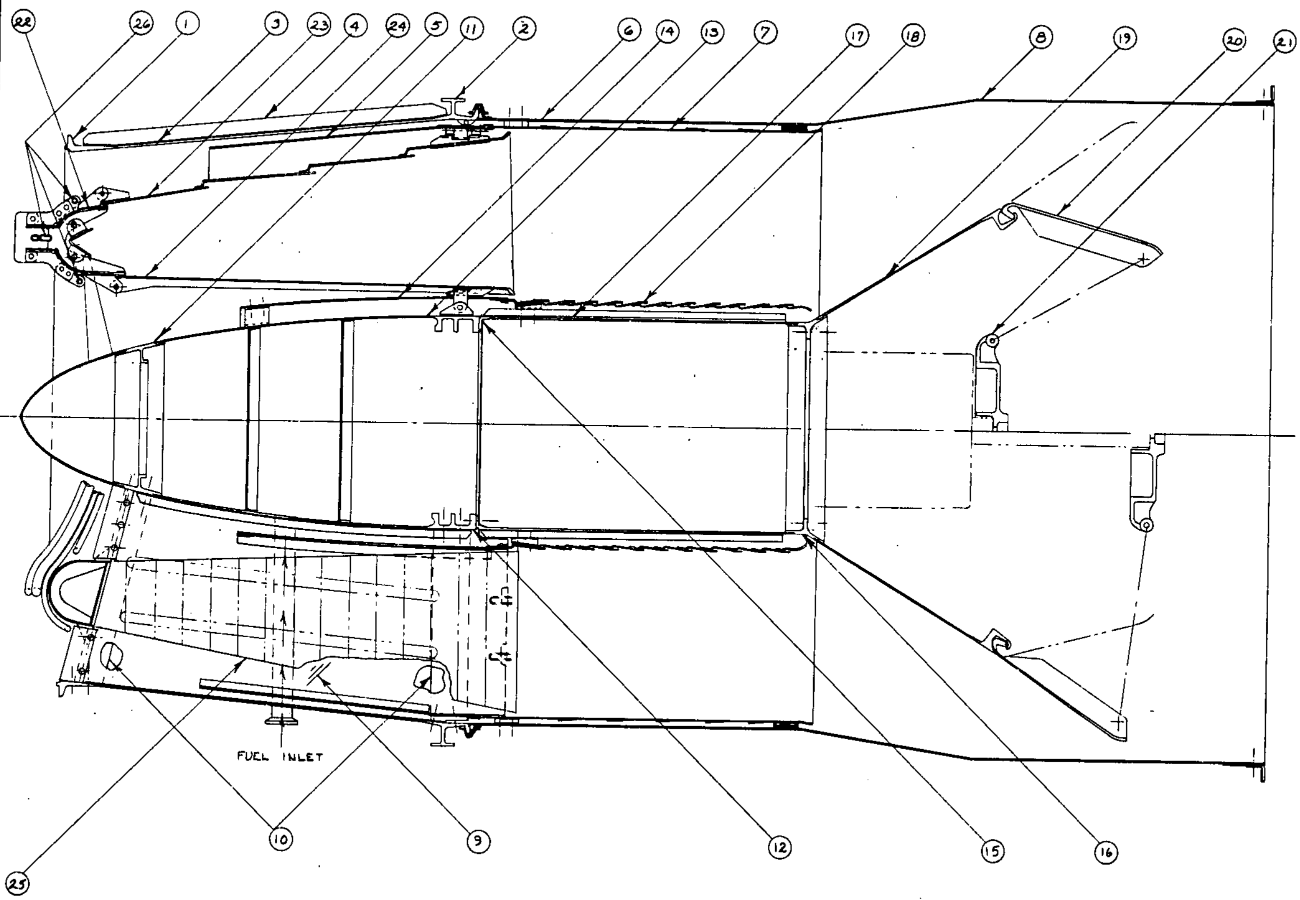

MACH 4.0 INTEGRAL CRUISE ENGINE
COMBUSTOR PERFORMANCE
30 INCH ENGINE
COMBUSTION EFFICIENCY
M0 = 2.0
ALTITUDE = 36,000 FT
M0 = 4.0
ALTITUDE = 90,000 FT
ESTIMATED VALUE
ESTIMATED VALUE
COMBUSTION EFFICIENCY ~ ηc ~ %
COMBUSTOR BURNER DRAG DOCUMENTATION
ESTIMATED OPERATING RANGE
BURNER DRAG COEFFICIENT ~ CDB
M2 ~ COMBUSTOR INLET MACH NUMBER (THEORETICAL)


INTEGRAL CRUISE TYPE RAMJET
MAJOR SUB-ASSEMBLIES
OUTER COMBUSTOR-NOZZLE SHELL
OPEN
VARIABLE EXIT
CLOSED
COOLING LINERS
CENTER BODY ASSEMBLY
FORWARD OUTER
STRUCTURAL ASSEMBLY
ANNULAR CAN
FLAMEHOLDER

MAC A673

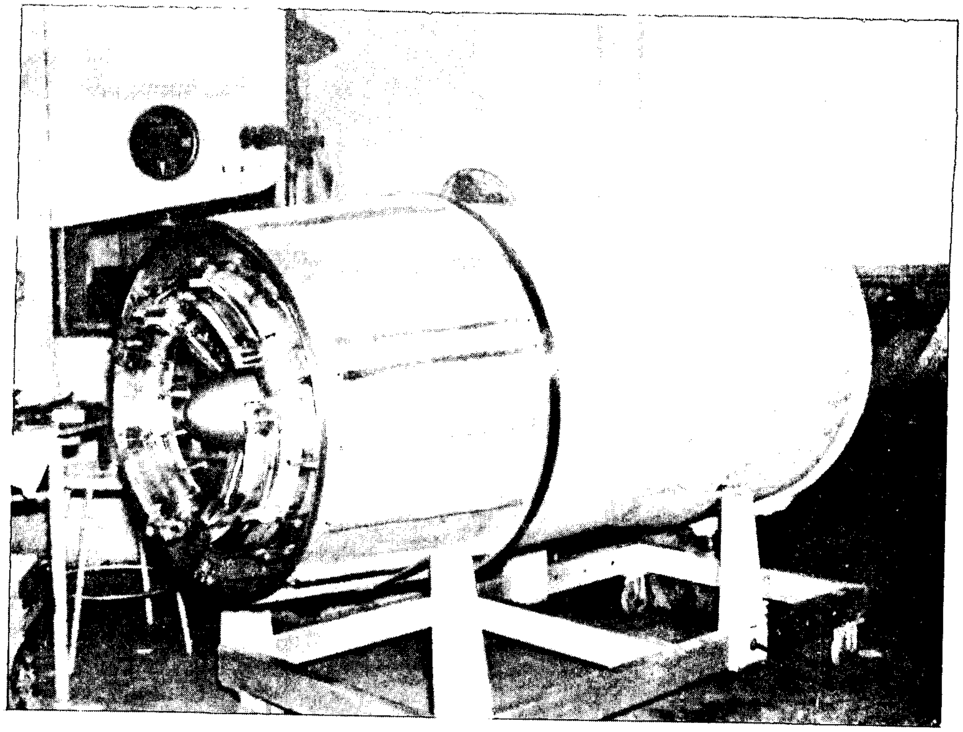

INTEGRAL CRUISE TYPE RAMJET
MAXIMUM OPERATING METAL TEMPERATURES
DEGREES FAHRENHEIT
1750
1780
1580
1100
1780
1560
1840
1880
1540
1800°
1800°
1350
1400
1250
1350

MATERIAL SELECTIONS

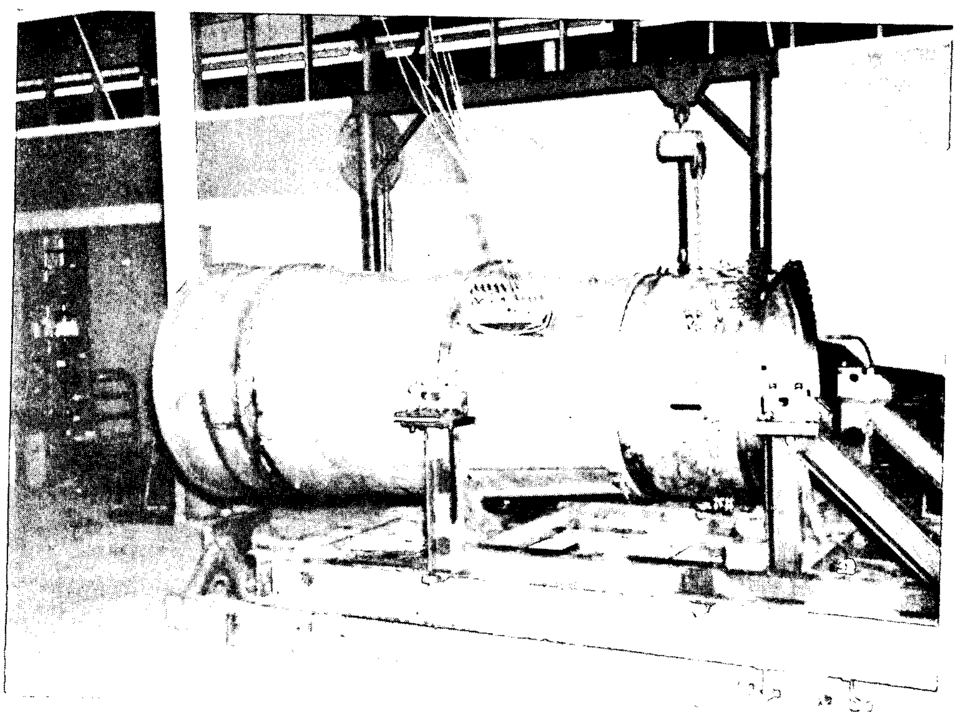


ITEM NO.	MATERIAL				
	RENE 41 SHEET	RENE 41 BAR	HASTELLOY W	321 STAINLESS	713C CASTING
1	--	X	--	--	--
2	--	X	--	--	--
3	X	--	--	--	--
4	X	--	--	--	--
5	X	--	--	--	--
6	X	--	--	--	--
7	X	--	--	--	--
8	X	--	--	--	--
9	X	--	--	--	--
10	X	--	--	--	--
11	--	--	--	--	X
12	--	X	--	--	--
13	X	--	--	--	--
14	X	--	--	--	--
15	--	X	--	--	--
16	--	X	--	--	--
17	X	--	--	--	--
18	X	--	--	--	--
19	X	--	--	--	--
20	--	--	--	--	X
21	--	--	--	--	X
22	X	--	--	--	--
23	--	--	X	--	--
24	--	--	X	--	--
25	--	--	X	--	--
26	--	X	--	--	--

MAC A673



P39-5

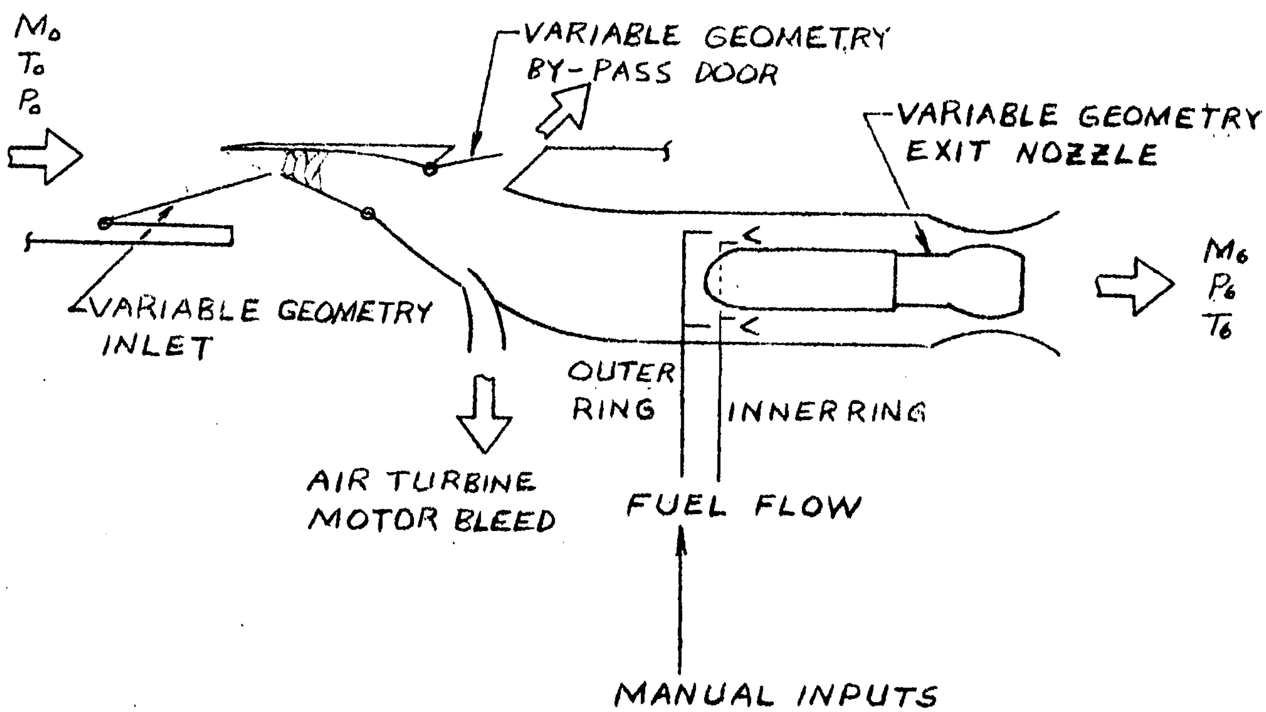


P41-6

FIGURE 16 - Prototype of Flight Engine

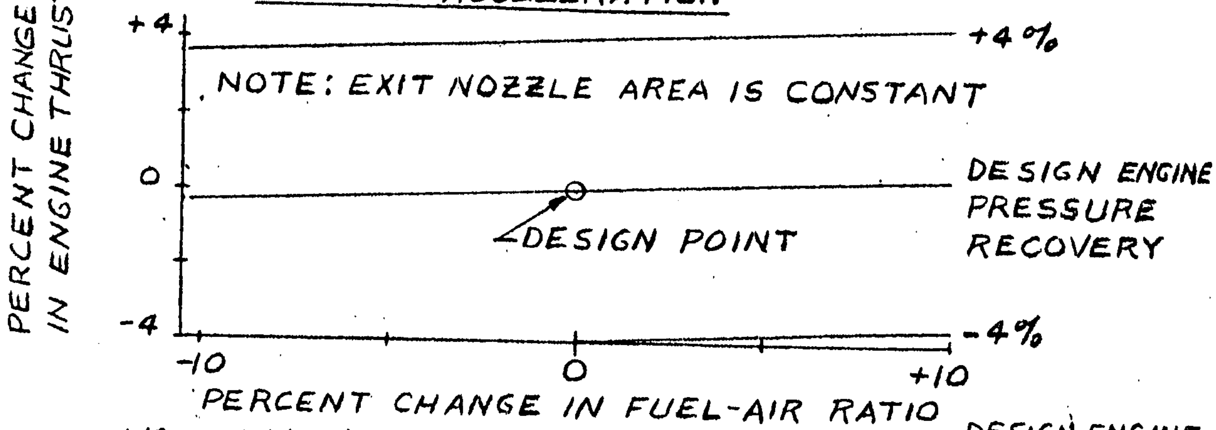
MAC A673

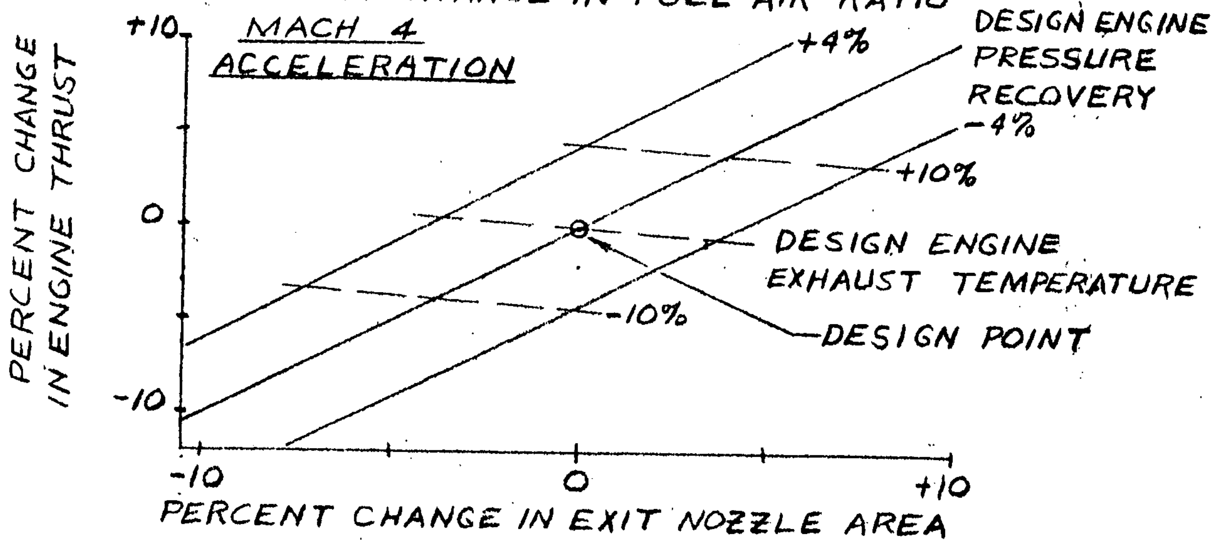
SCHEMATIC -
PROPULSION SYSTEM INPUTS AND
VARIABLES FOR CONTROL



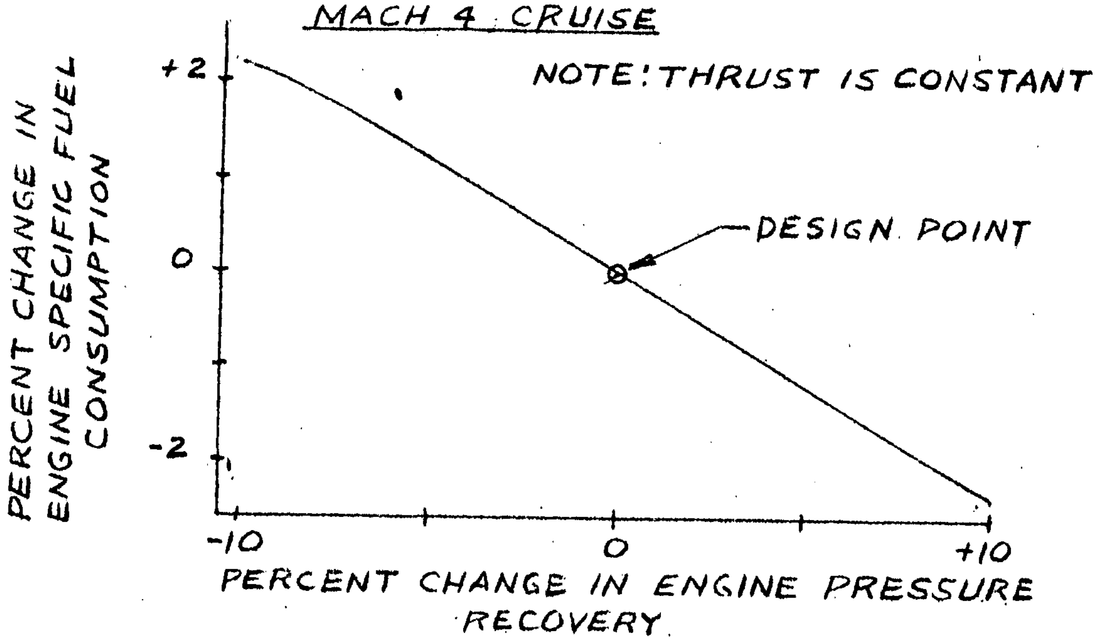
THRUST AND SPECIFIC FUEL CONSUMPTION SENSITIVITY TO ENGINE PERFORMANCE CHARACTERISTICS

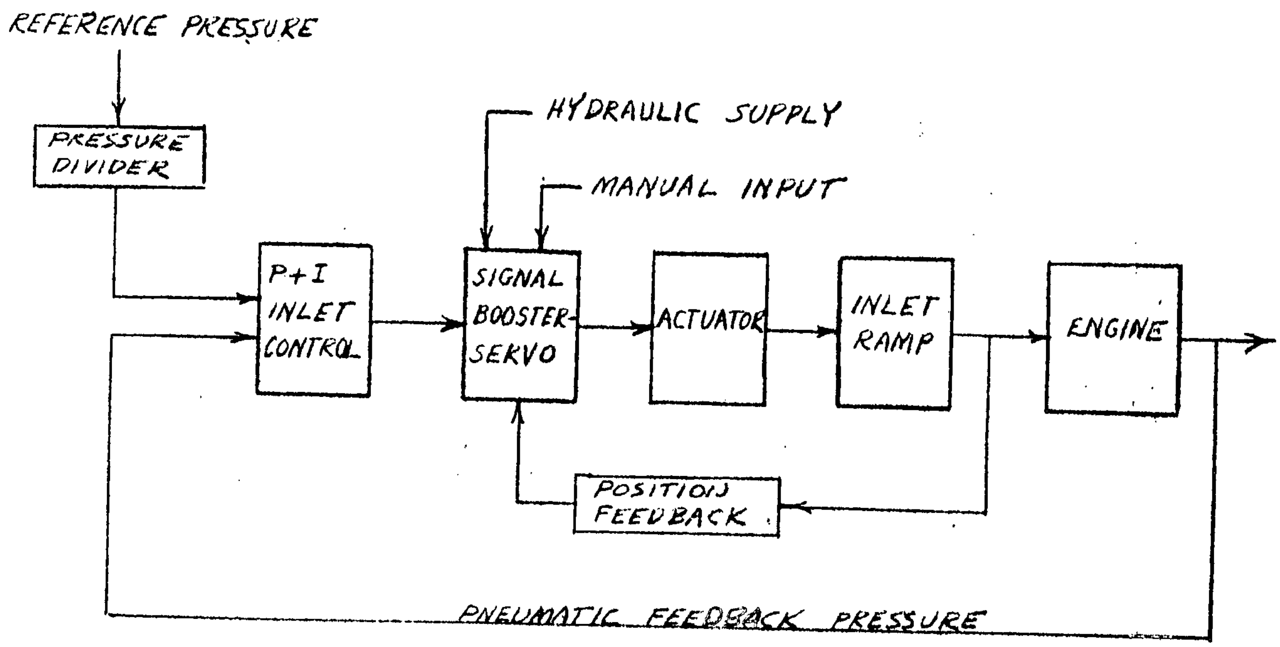
MACH 2 ACCELERATION





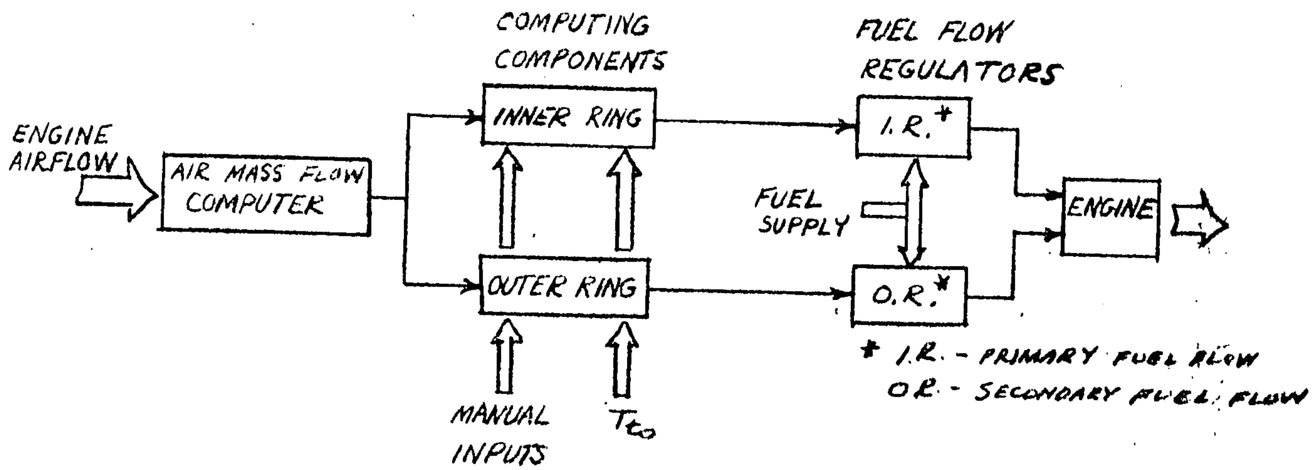
MACH 4 CRUISE



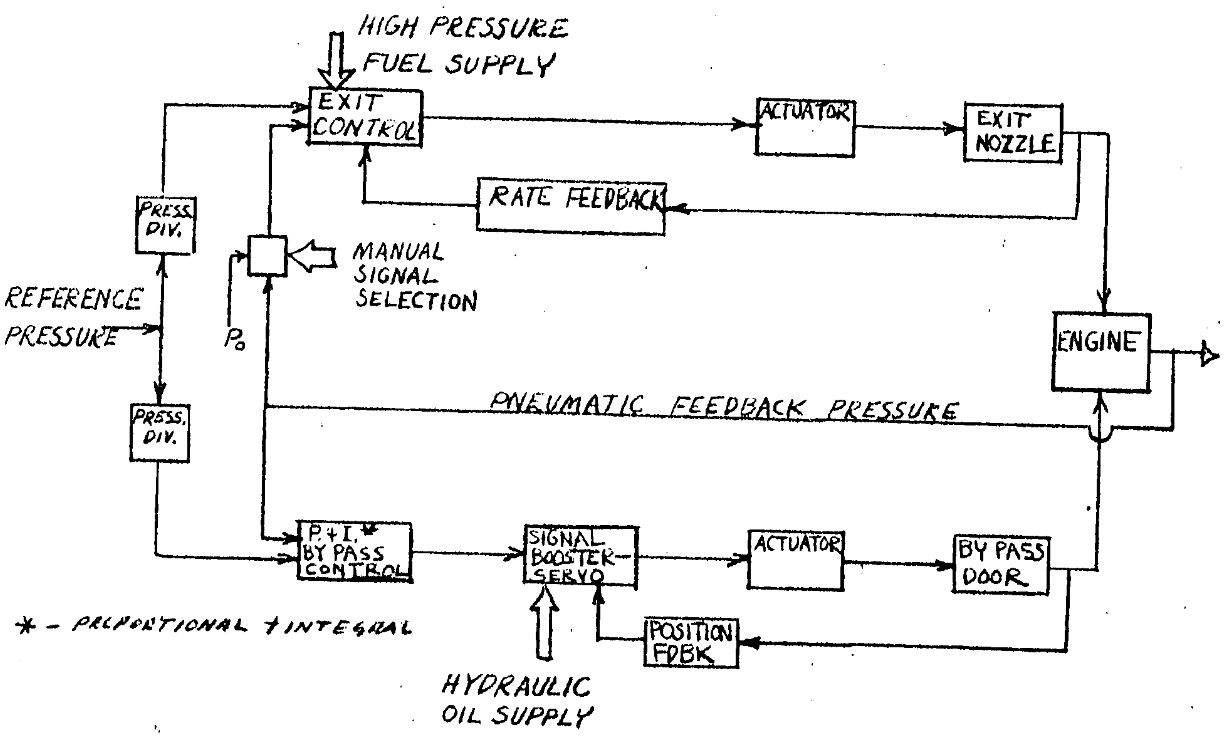


INLET GEOMETRY CONTROL SYSTEM

BLOCK DIAGRAM OF CONTROL SYSTEM



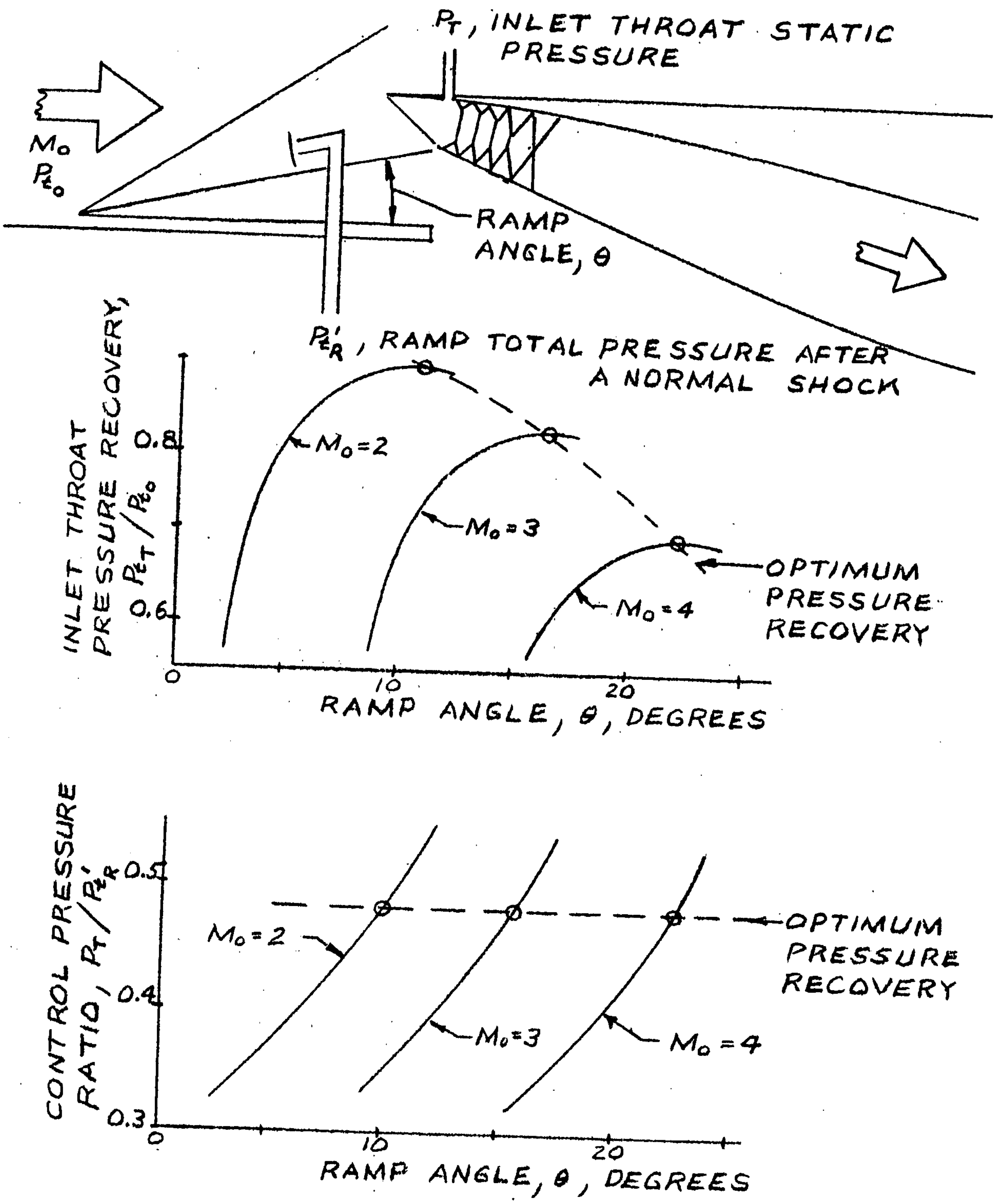
ENGINE FUEL CONTROL SYSTEM

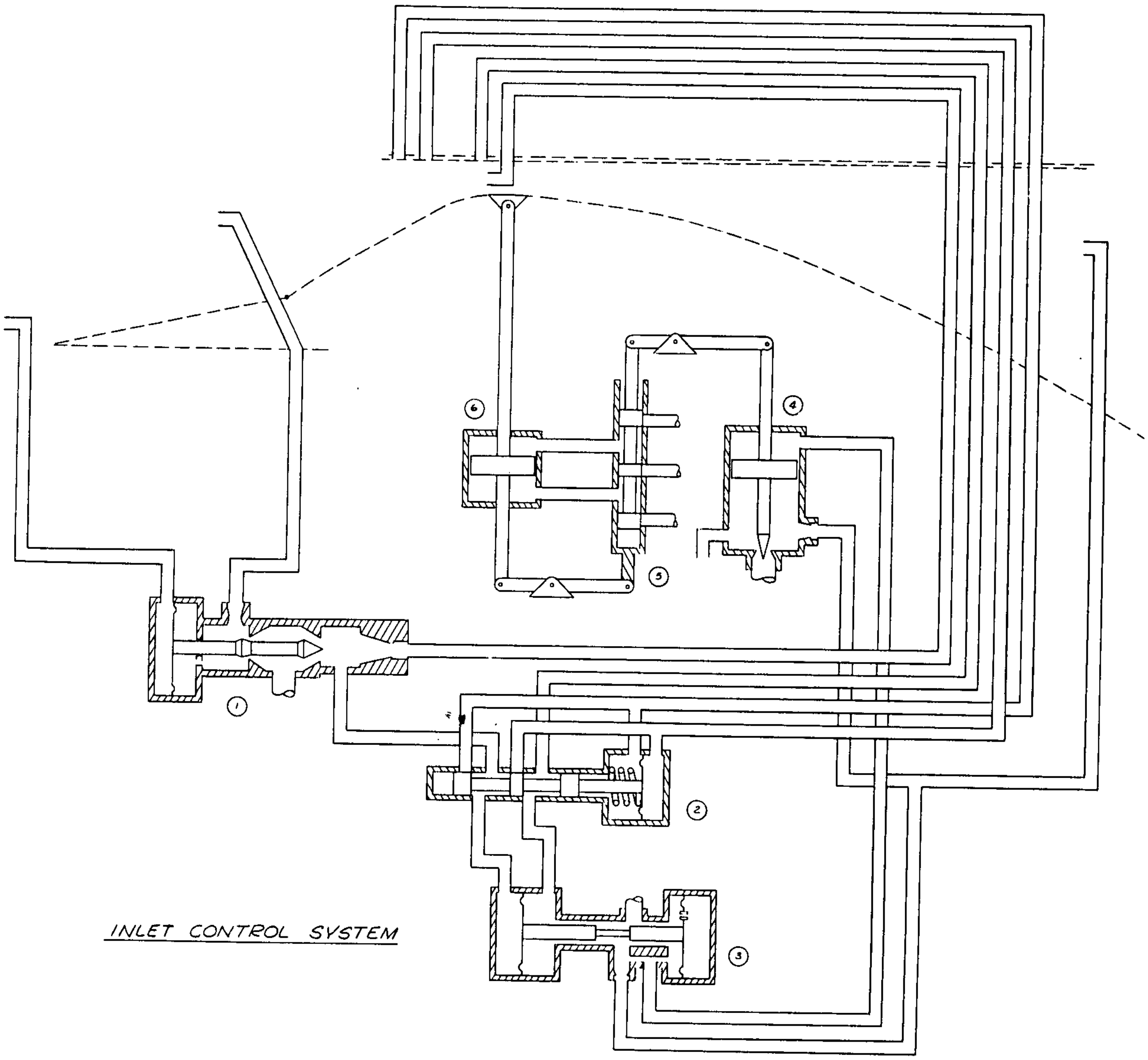


EXIT NOZZLE AND BY-PASS DOOR CONTROL SYSTEM

BLOCK DIAGRAM OF CONTROL SYSTEM

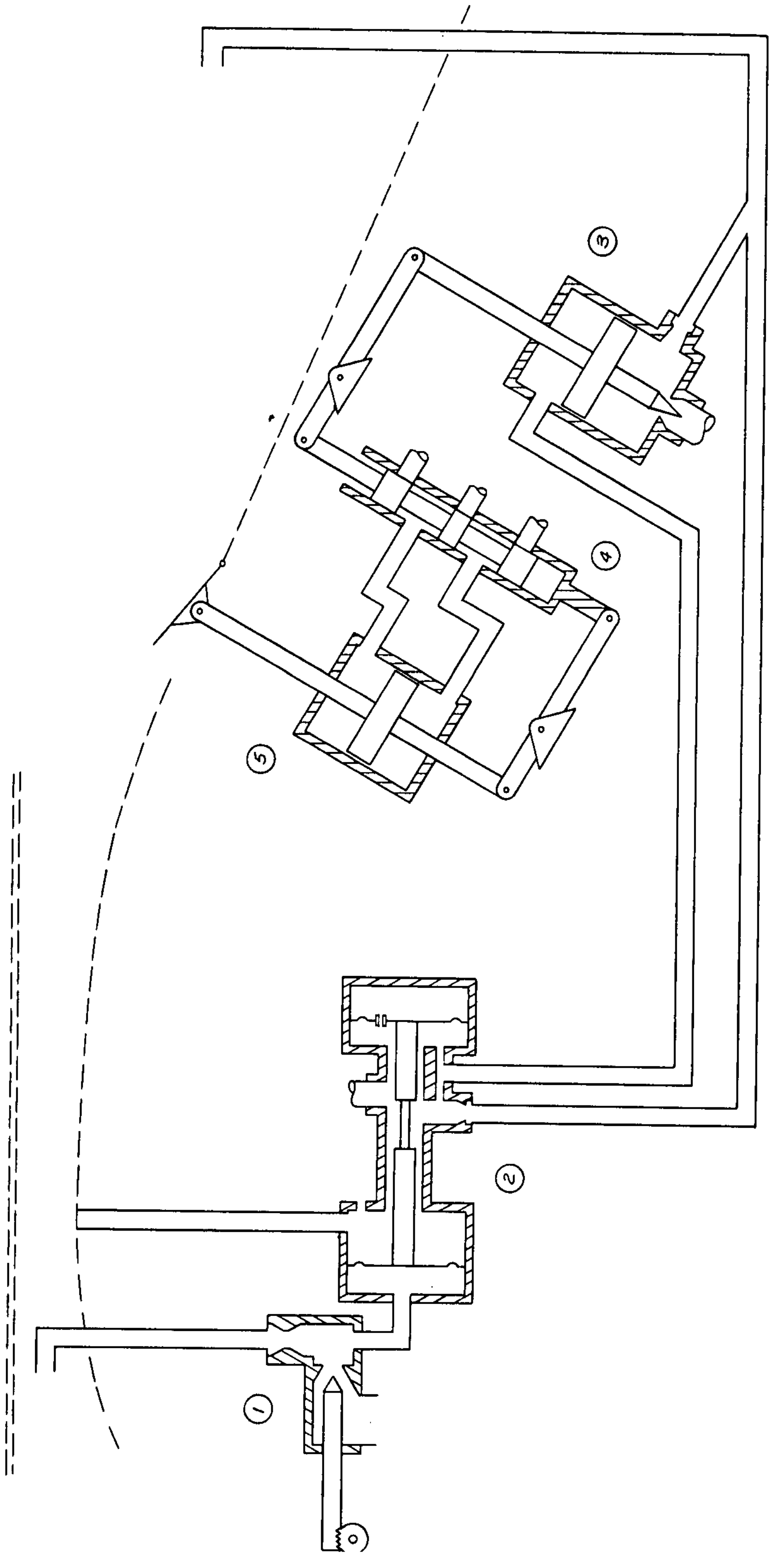
SIGNAL PARAMETER SUITABILITY- INLET CONTROL SYSTEM





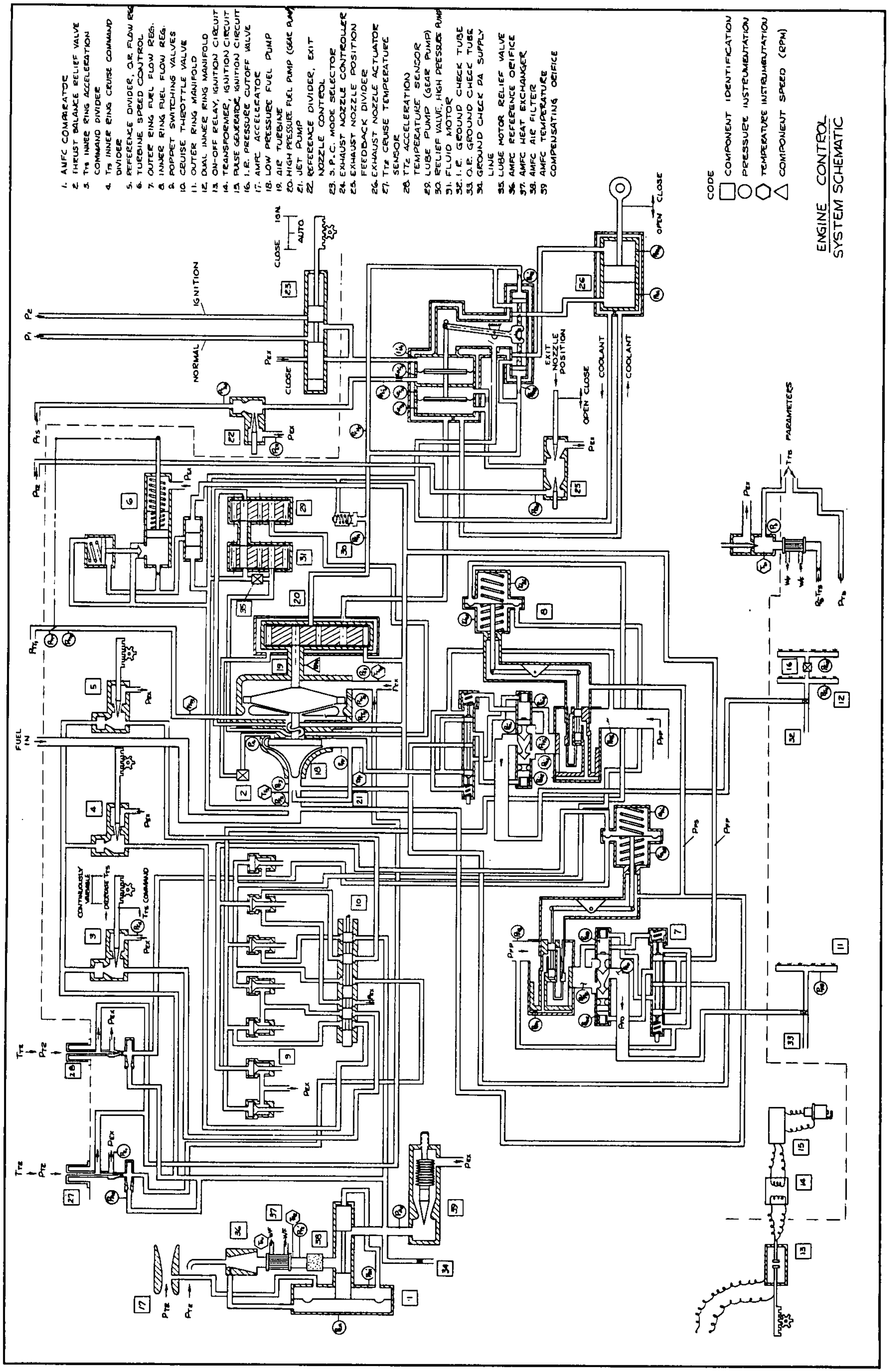
INLET CONTROL SYSTEM

1 MACH SCHEDULER
2 MODE SELECTER
3 INLET CONTROLLER
4 POWER BOOSTER
5 INLET SERVO VALVE
6 INLET ACTUATOR



BYPASS CONTROL SYSTEM

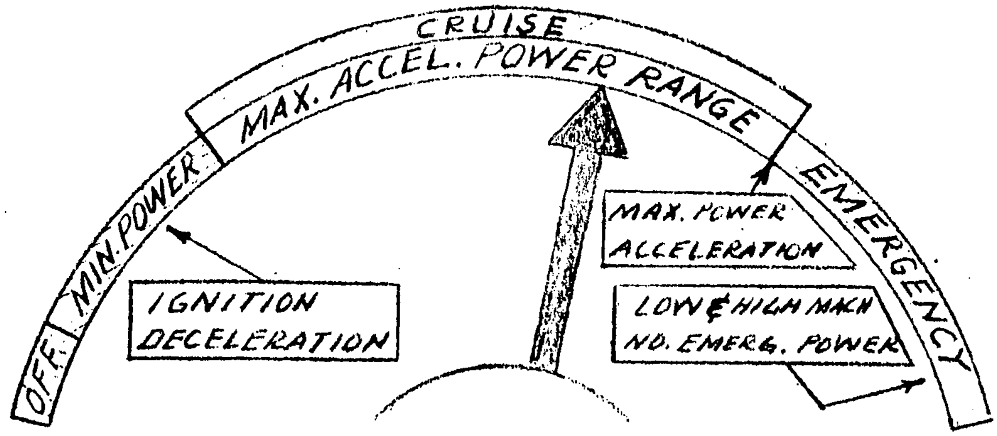
1 REFERENCE PRESSURE DIVIDER
2 BYPASS CONTROLLER
3 POWER BOOSTER
4 BYPASS SERVO VALVE
5 BYPASS ACTUATOR


1. AMFC COMPARATOR
2. THRUST BALANCE RELIEF VALVE
3. Tt5 INNER RING ACCELERATION COMMAND DIVIDER
4. Tt5 INNER RING CRUISE COMMAND DIVIDER
5. REFERENCE DIVIDER, O.R. FLOW REG.
6. TURBINE SPEED CONTROL
7. OUTER RING FUEL FLOW REG.
8. INNER RING FUEL FLOW REG.
9. POPPET SWITCHING VALVES
10. CRUISE THROTTLE VALVE
11. OUTER RING MANIFOLD
12. DUAL INNER RING MANIFOLD
13. ON-OFF RELAY, IGNITION CIRCUIT
14. TRANSFORMER, IGNITION CIRCUIT
15. PULSE GENERATOR, IGNITION CIRCUIT
16. I.R. PRESSURE CUTOFF VALVE
17. AMFC ACCELERATOR
18. LOW PRESSURE FUEL PUMP
19. AIR TURBINE
20. HIGH PRESSURE FUEL PUMP (GEAR PUMP)
21. JET PUMP
22. REFERENCE DIVIDER, EXIT NOZZLE CONTROL
23. S.P.C. MODE SELECTOR
24. EXHAUST NOZZLE CONTROLLER
25. EXHAUST NOZZLE POSITION FEEDBACK DIVIDER
26. EXHAUST NOZZLE ACTUATOR
27. Tt2 CRUISE TEMPERATURE SENSOR
28. Tt2 ACCELERATION TEMPERATURE SENSOR
29. LUBE PUMP (GEAR PUMP)
30. RELIEF VALVE, HIGH PRESSURE PUMP
31. FLUID MOTOR
32. I.R. GROUND CHECK TUBE
33. O.R. GROUND CHECK TUBE
34. GROUND CHECK PA SUPPLY LINE
35. LUBE MOTOR RELIEF VALVE
36. AMFC REFERENCE ORIFICE
37. AMFC HEAT EXCHANGER
38. AMFC AIR FILTER
39. AMFC TEMPERATURE COMPENSATING ORIFICE
CODE
COMPONENT IDENTIFICATION
PRESSURE INSTRUMENTATION
TEMPERATURE INSTRUMENTATION
COMPONENT SPEED (RPM)
FUEL IN
IGNITION
NORMAL
CLOSE
AUTO
EXIT NOZZLE POSITION
OPEN
COOLANT
PARAMETERS
ENGINE CONTROL SYSTEM SCHEMATIC

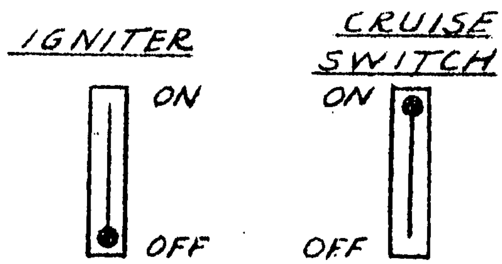
MAC A673

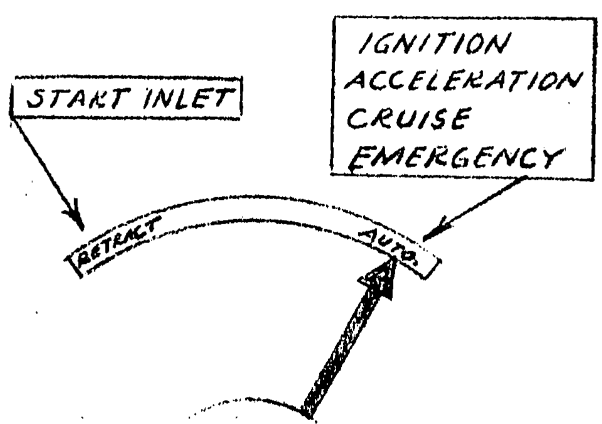
MANUAL INPUTS

PROPULSION CONTROL SYSTEM

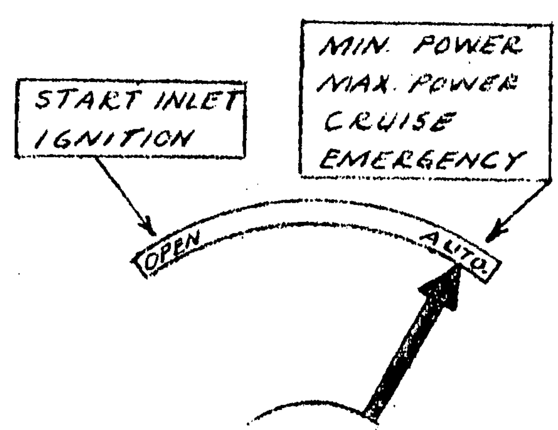


POWER THROTTLE



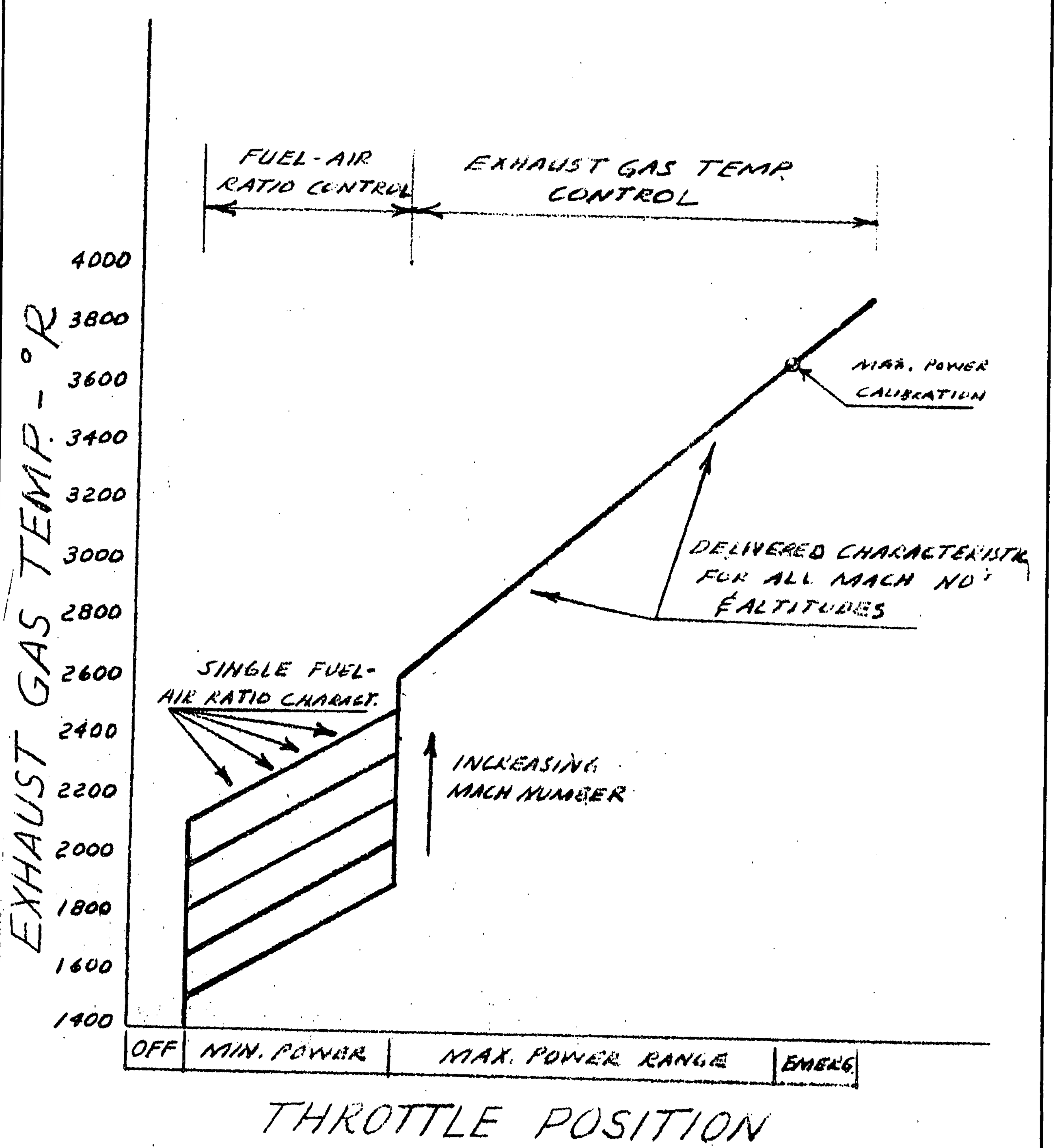


INLET



EXIT NOZZLE & BY-PASS

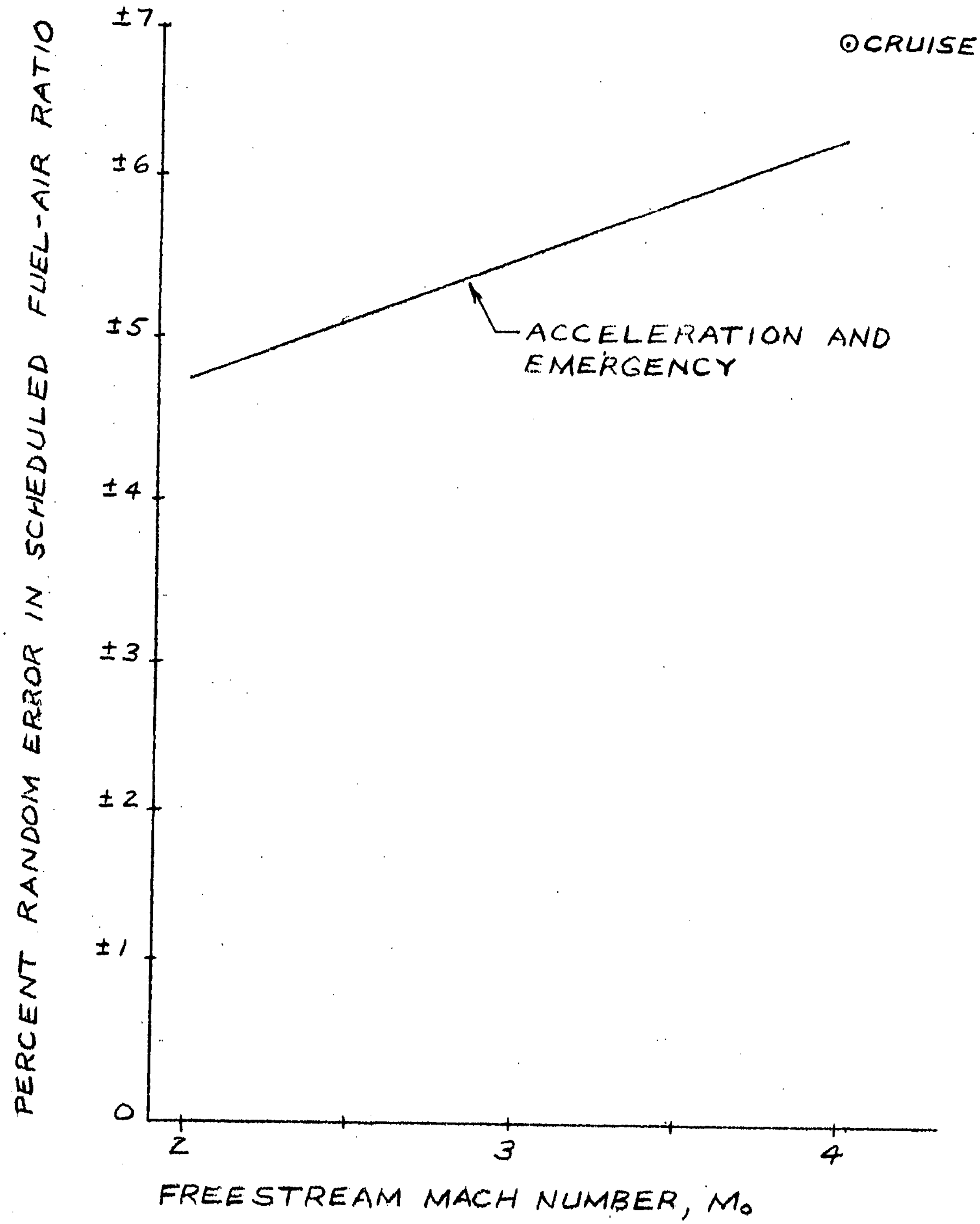
CONTROLLED ENGINE OUTPUT POWER CHARACTERISTICS



MAC A673

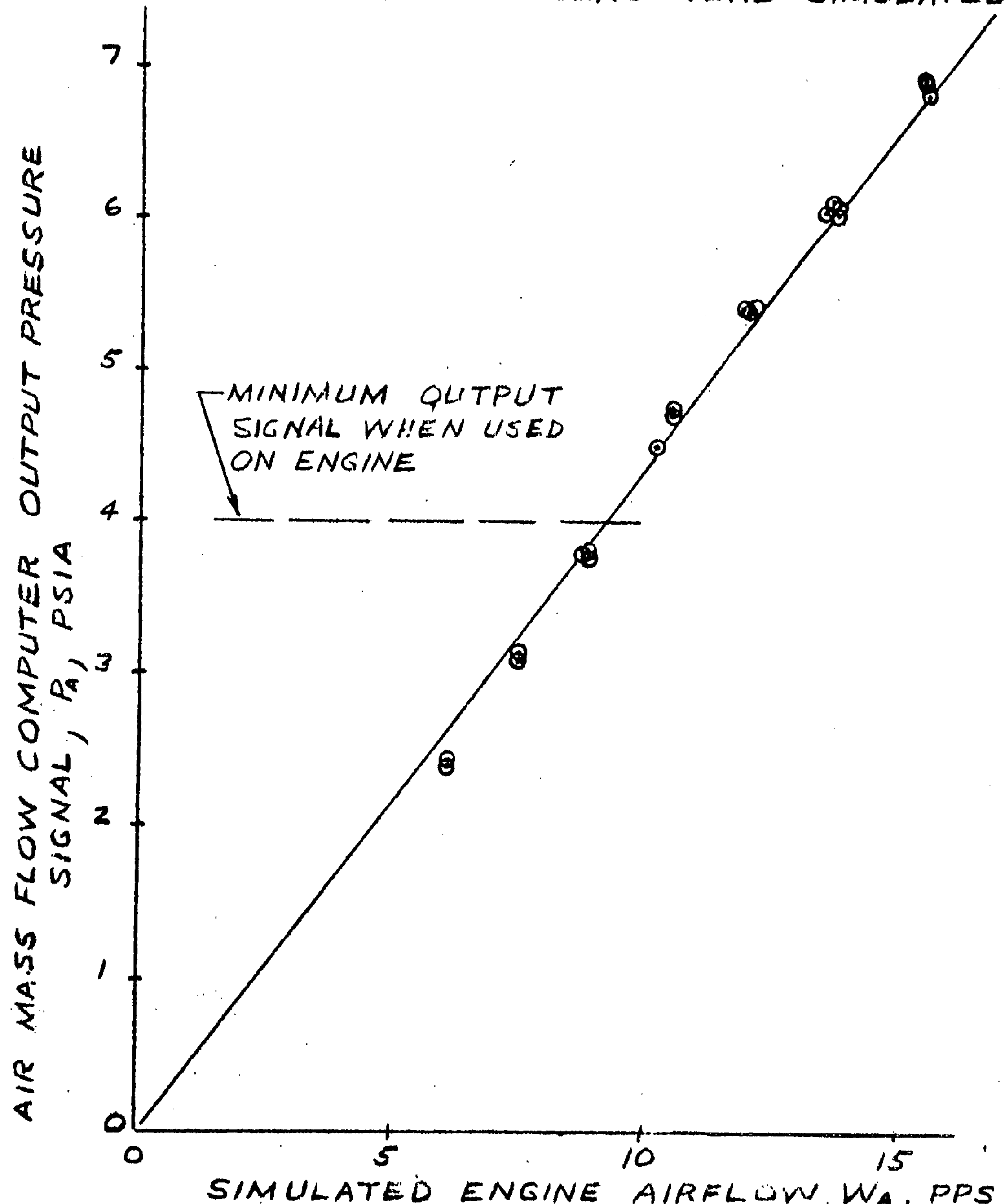
PREDICTED ACCURACY - ENGINE CONTROL SYSTEM - FUEL - AIR RATIO LOOP

NOTE: RANDOM ERROR LIMIT IS $\pm 2\sigma$

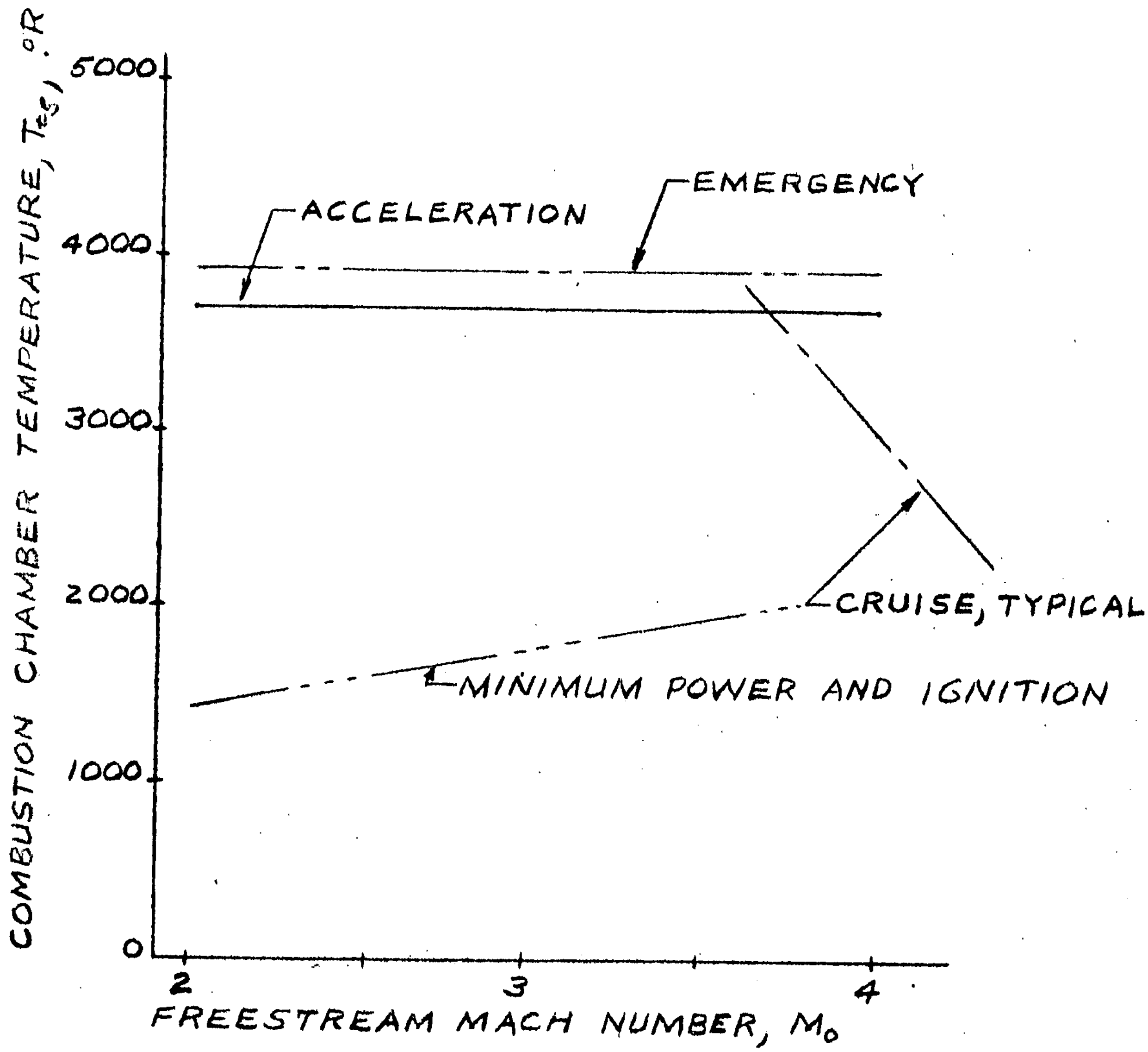


AIR MASS FLOW COMPUTER PERFORMANCE

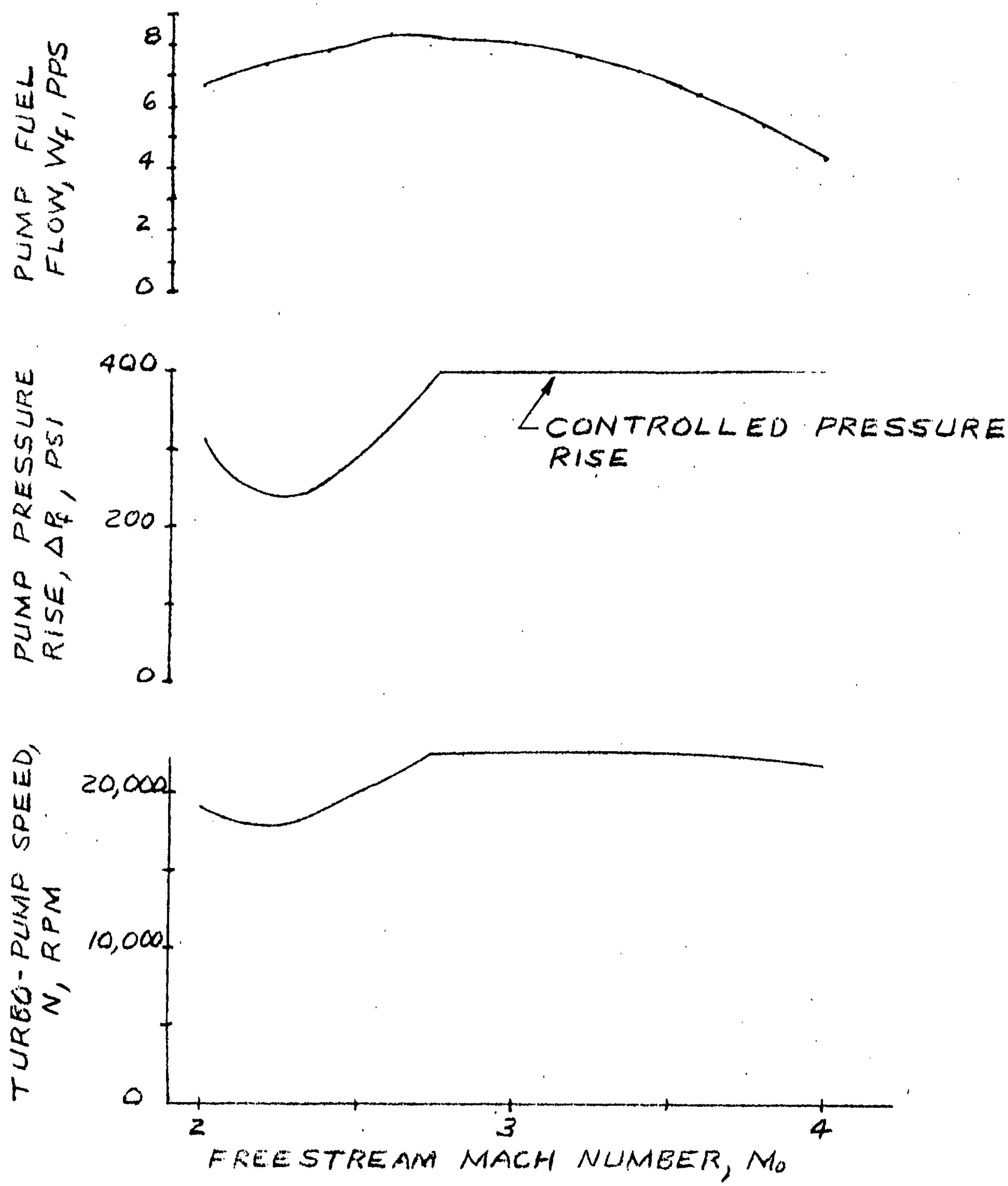
NOTE: 1. HIGH ALTITUDE TEST (MOST SEVERE CONDITIONS)
2. COMPLETE RANGE OF ENGINE MACH NUMBERS WERE SIMULATED



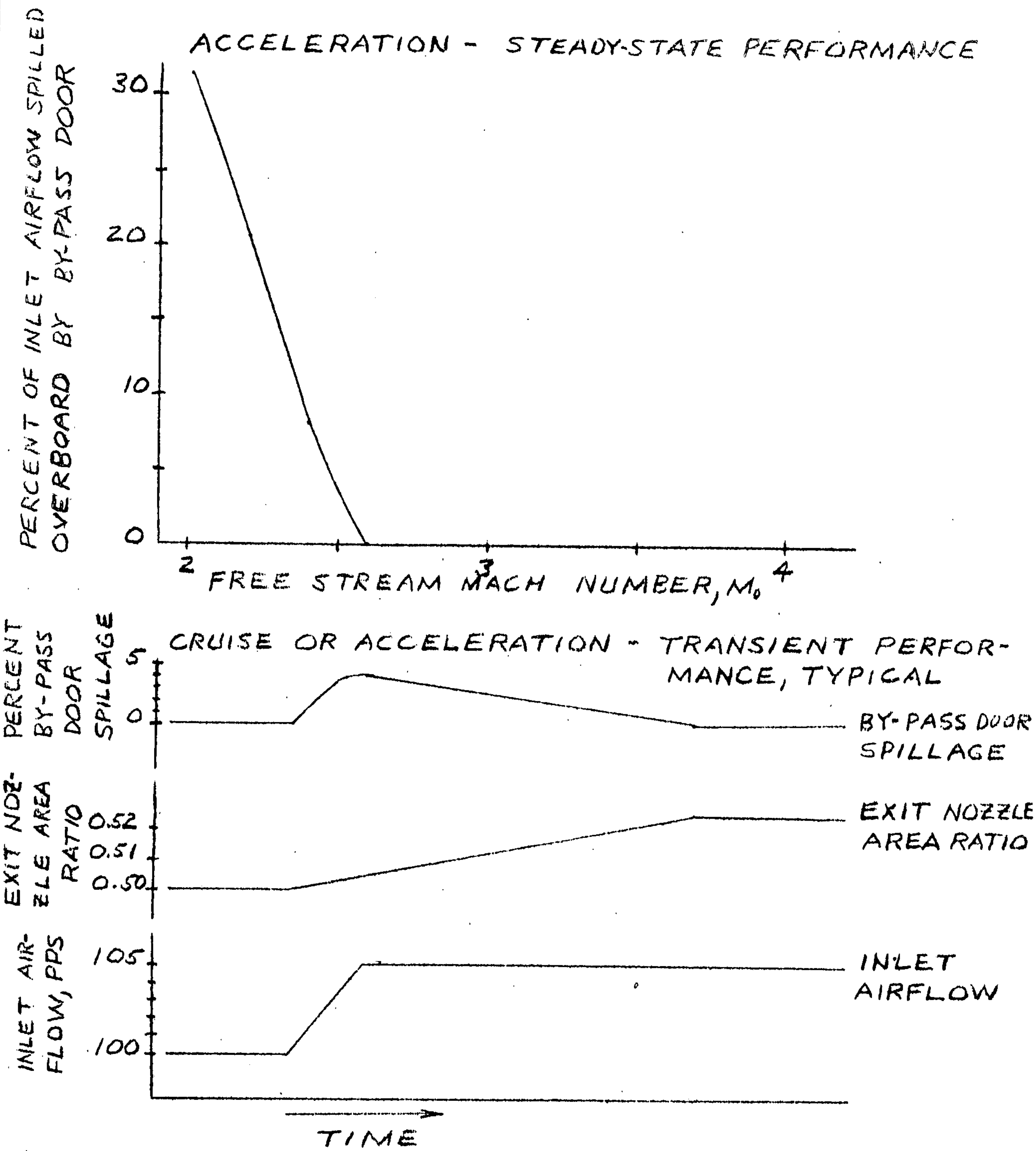
ACCELERATION AND CRUISE CONTROL CHARACTERISTICS OF COMBUSTION CHAMBER TEMPERATURE

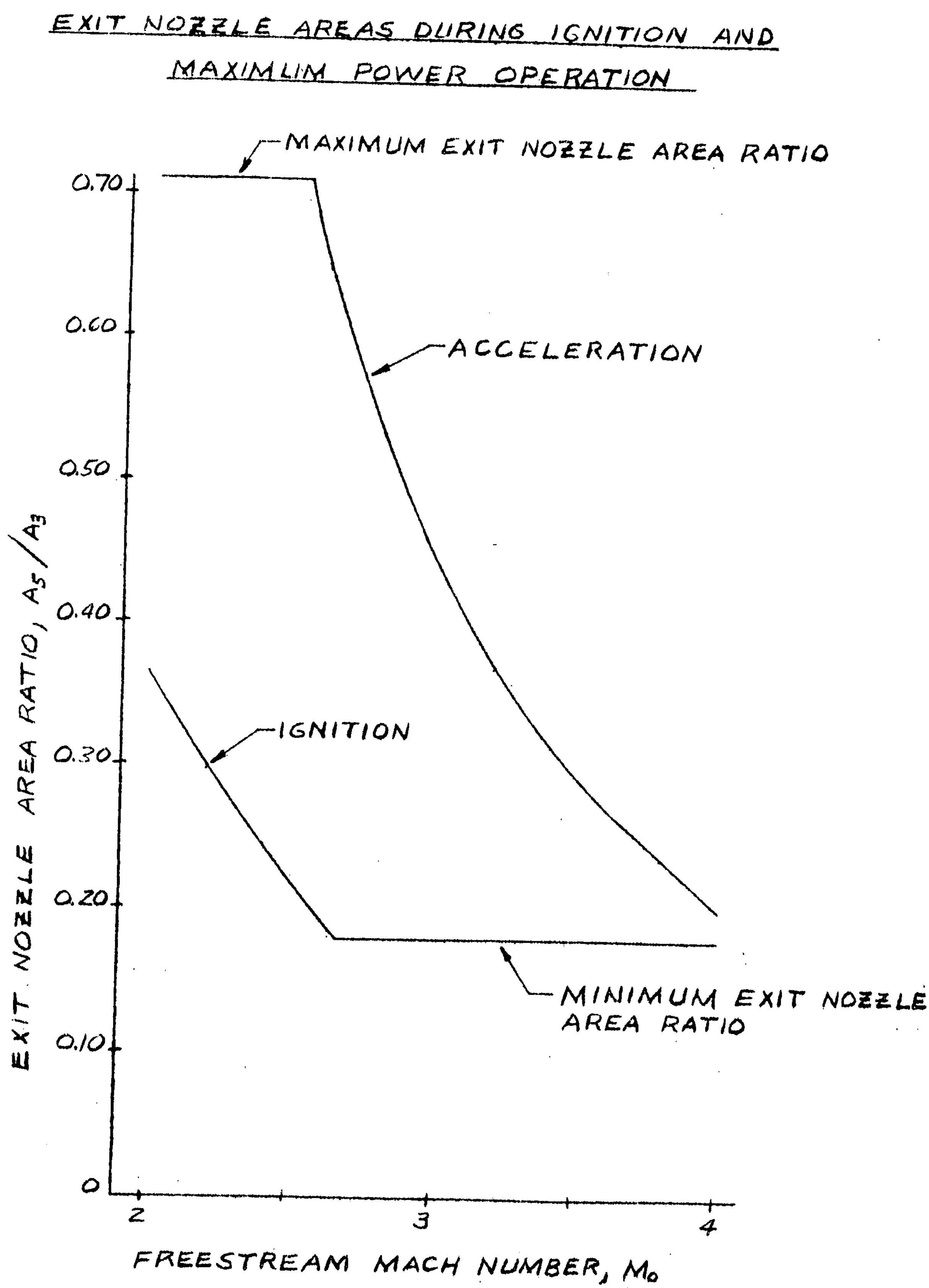


TURBO-PUMP FUEL FLOW, PRESSURE RISE, AND SPEED CHARACTERISTICS



BY-PASS DOOR OPERATING CHARACTERISTICS DURING STEADY-STATE AND TRANSIENT CONDITIONS




EXIT NOZZLE AREAS DURING IGNITION AND MAXIMUM POWER OPERATION
MAXIMUM EXIT NOZZLE AREA RATIO
ACCELERATION
IGNITION
MINIMUM EXIT NOZZLE AREA RATIO
EXIT NOZZLE AREA RATIO, A_5/A_3
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
2
3
4
FREESTREAM MACH NUMBER, M_0

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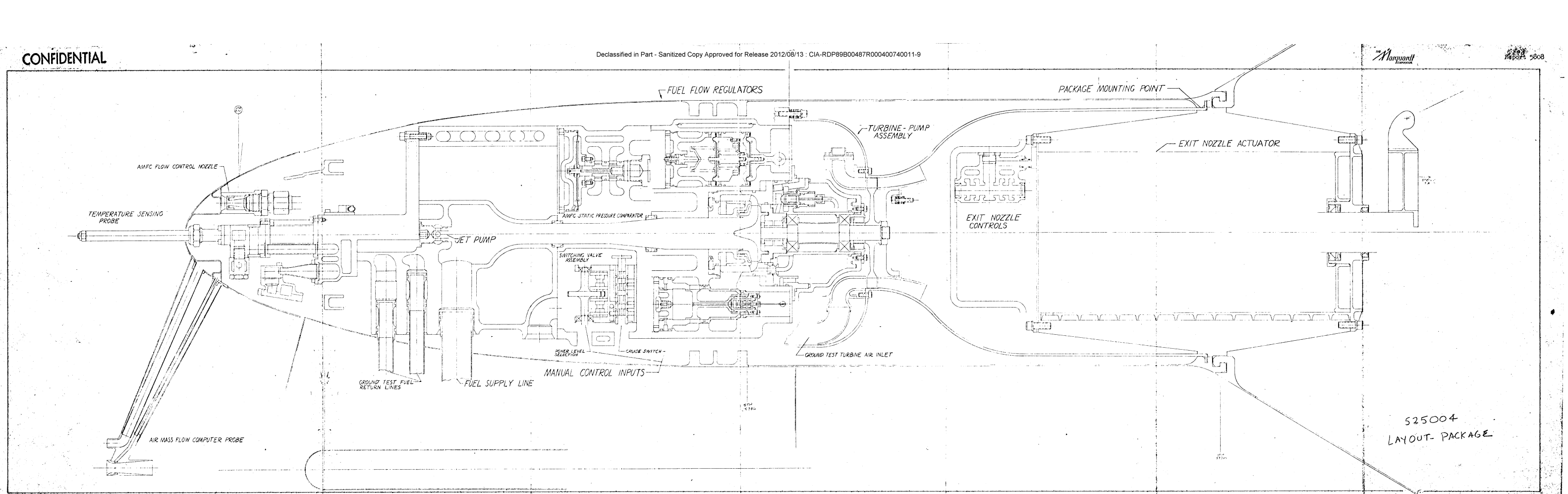
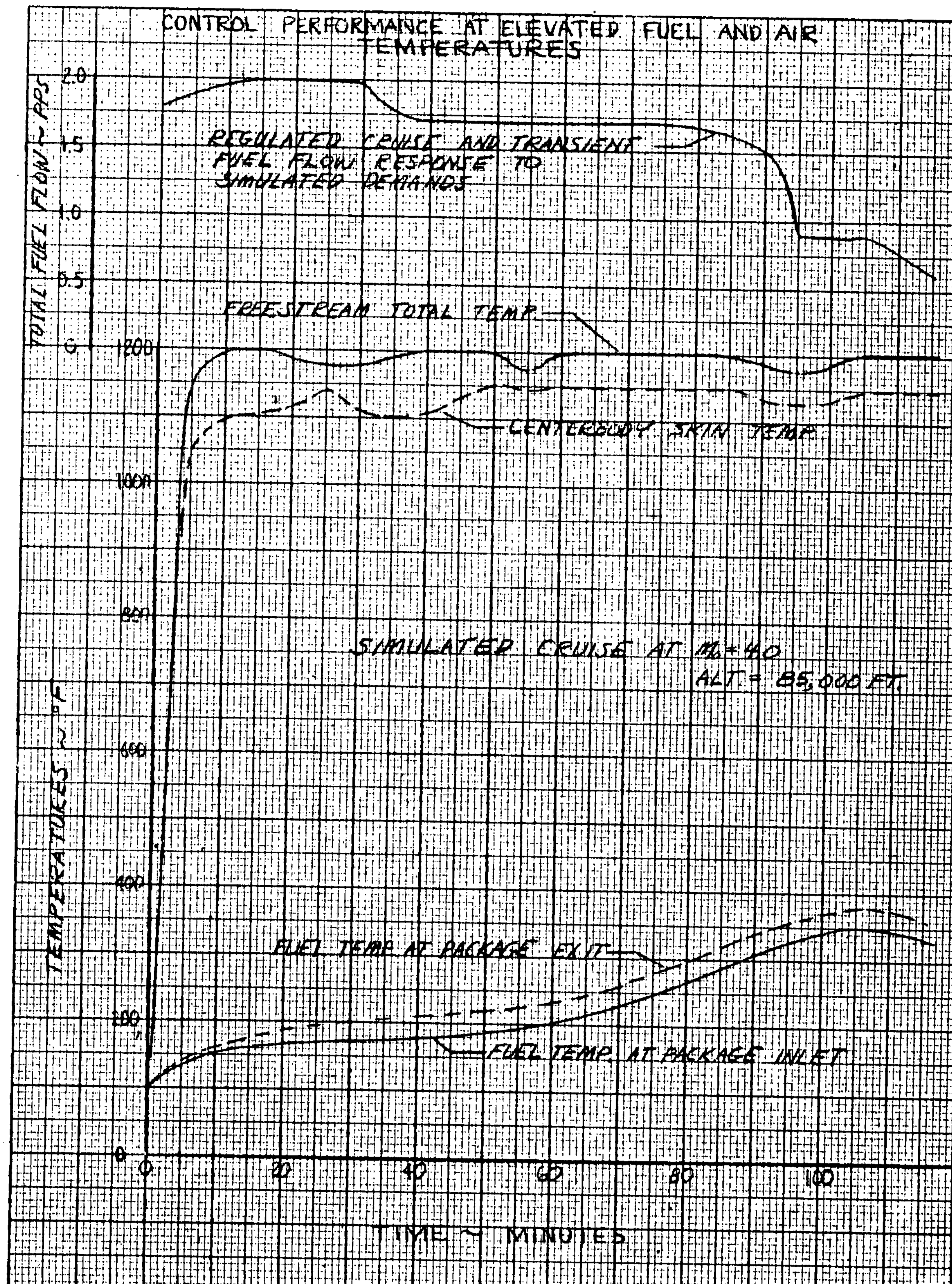


Declassified in Part - Sanitized Copy Approved for Release 2012/08/13 : CIA-RDP89B00487R000400740011-9



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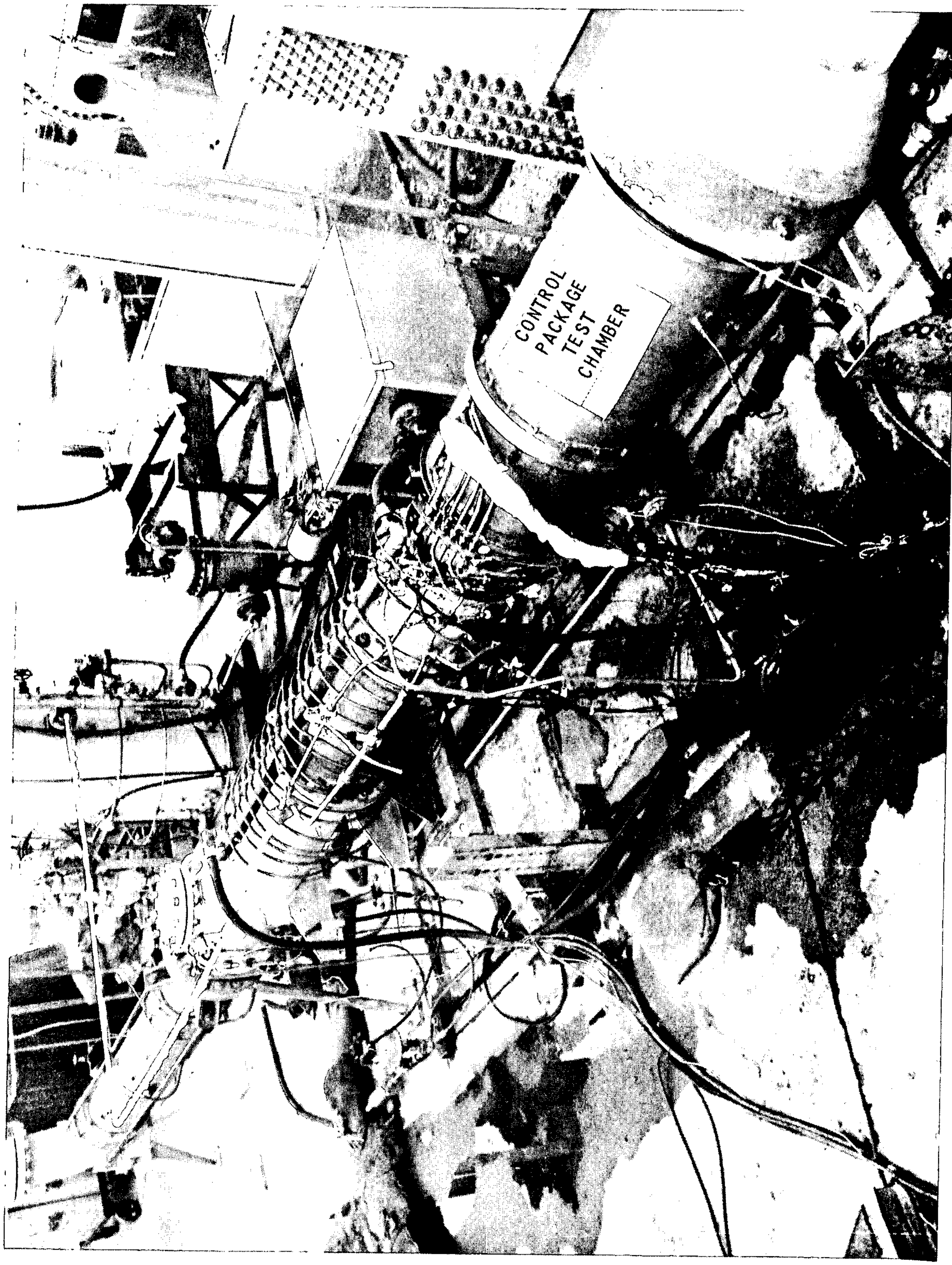
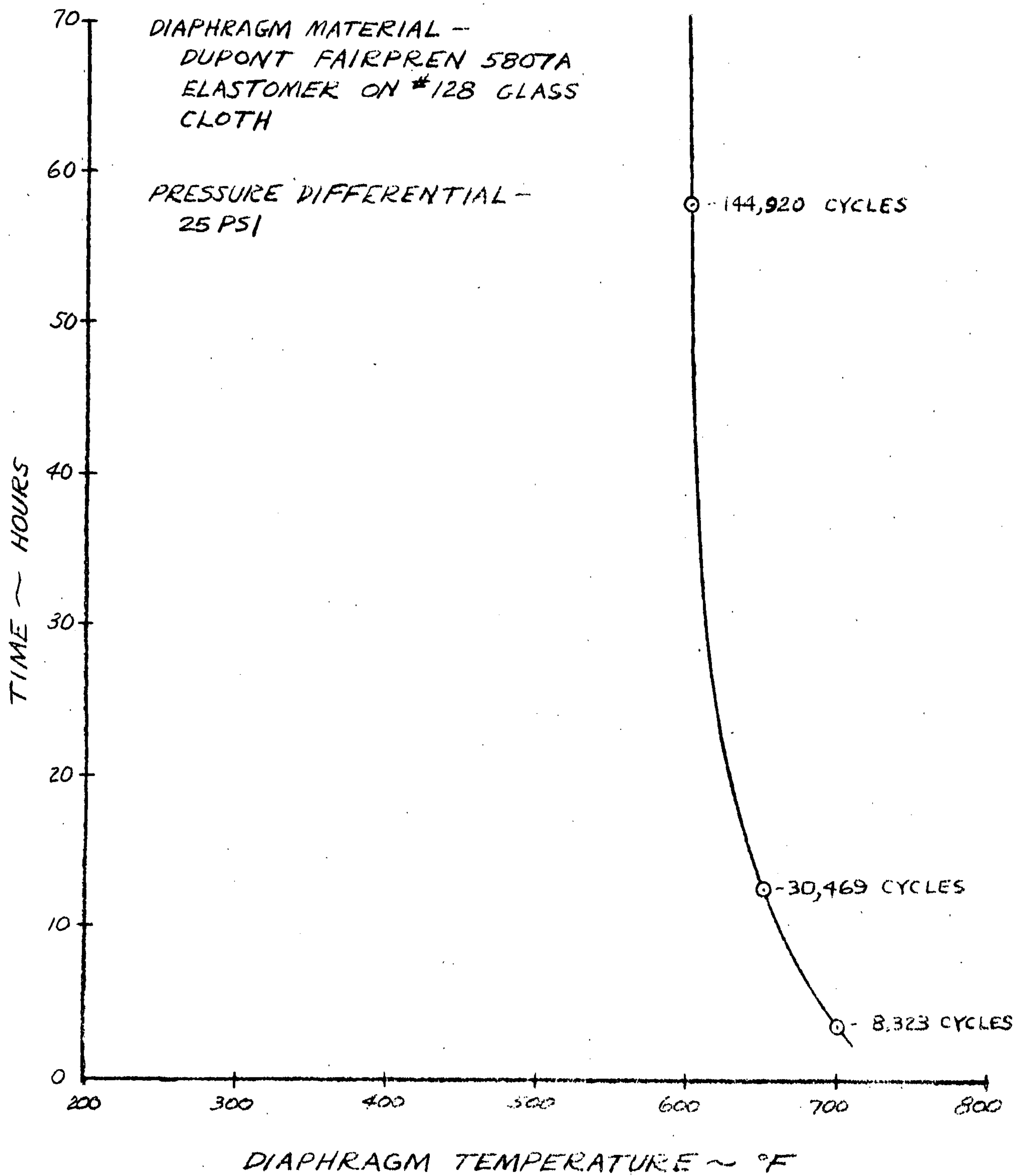
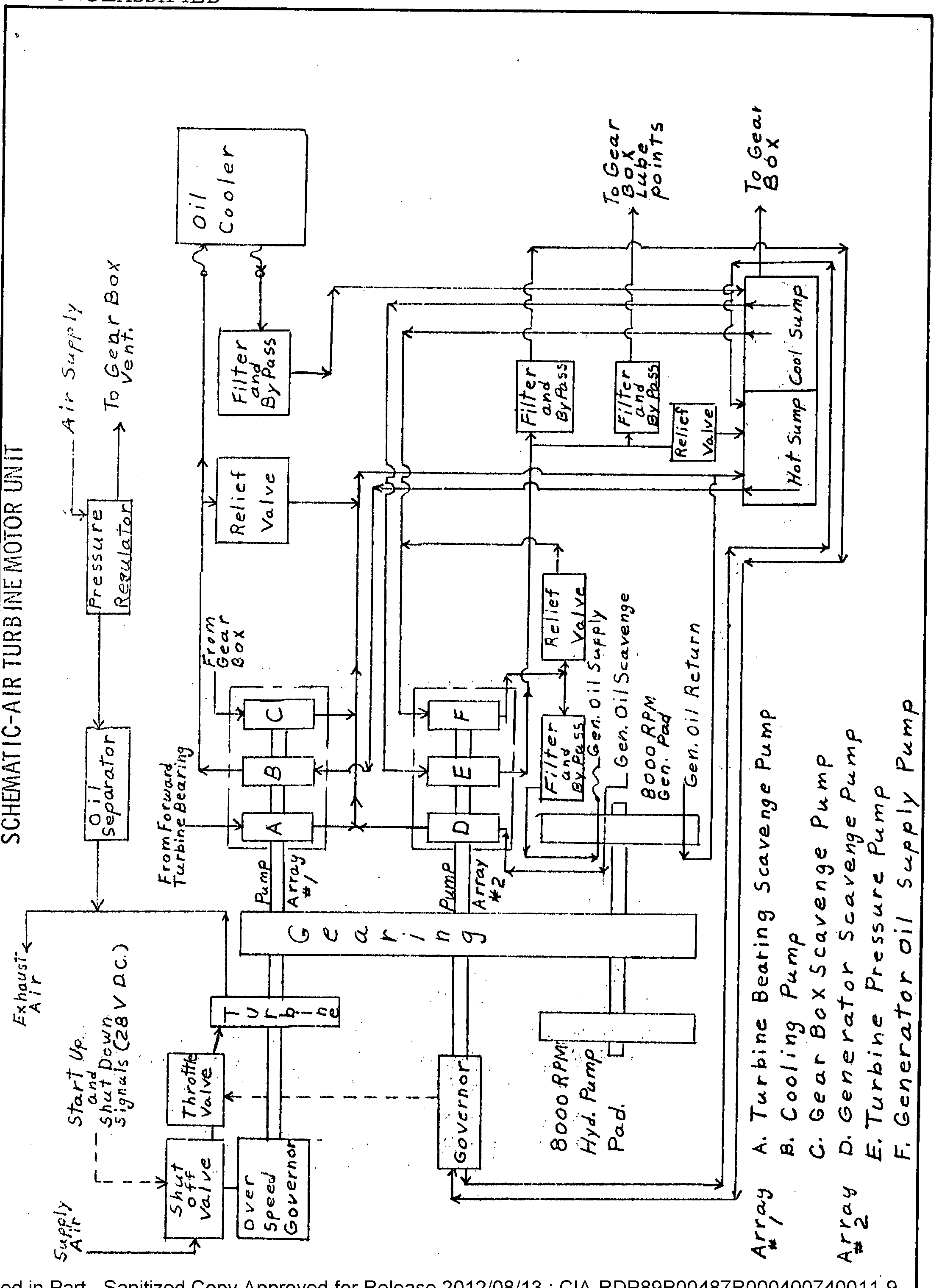


T2441-4

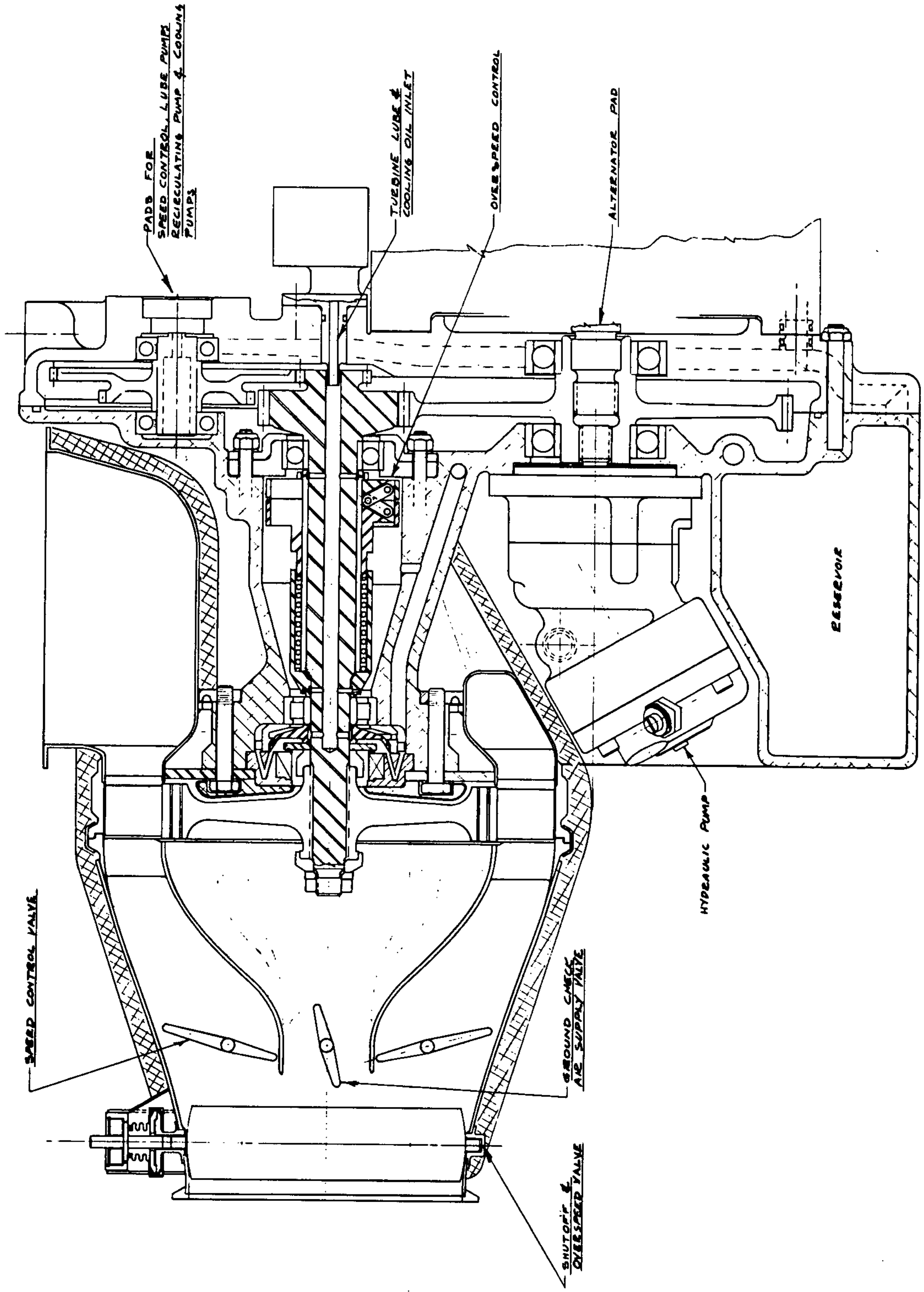
FIGURE 35 - Setup for Elevated Temperature Test of Control

DIAPHRAGM MOTOR LIFE - TEMPERATURE RELATIONSHIP




SCHEMATIC-AIR TURBINE MOTOR UNIT
Oil Cooler
To Gear Box Lube points
To Gear Box
Air Supply
To Gear Box Vent.
Filter and By Pass
Filter and By Pass
Filter and By Pass
Relief Valve
Relief Valve
Relief Valve
Cool Sump
Hot Sump
Pressure Regulator
Oil Separator
From Gear Box
From Forward Turbine Bearing
A
B
C
D
E
F
Pump Array #1
Pump Array #2
Gen. Oil Supply
Gen. Oil Scavenge
Gen. Oil Return
8000 RPM Gen. Pad
Gearing
Exhaust Air
Turbine
Start Up and Shut Down Signals (28 V D.C.)
Throttle Valve
Governor
Shut off Valve
Over Speed Governor
Supply Air
8000 RPM Hyd. Pump Pad.
Array #1 A. Turbine Bearing Scavenge Pump
B. Cooling Pump
C. Gear Box Scavenge Pump
Array #2 D. Generator Scavenge Pump
E. Turbine Pressure Pump
F. Generator Oil Supply Pump

AIR TURBINE MOTOR UNIT



APPENDIX A

PRELIMINARY
ENGINE MODEL SPECIFICATION
INCLUDING AIR INDUCTION CONTROL
AND ACTUATION SYSTEM

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

AC A673

ILLUSTRATIONS (Continued)

INTRODUCTION

This specification defines the requirements for PFRT of an integral ramjet engine including air induction control and actuation system.

SECTION I - ENGINE MODEL SPECIFICATION

1. GENERAL DESCRIPTION

1.1. The ramjet engine shall be of nominal 38-inch combustion chamber diameter and shall consist of a burner entrance section, combustion chamber, variable throat area exhaust nozzle, fuel pumping system, fuel and exhaust nozzle control systems, fuel distribution system, flame holder and ignition systems.

1.2. The engine physical and performance characteristics are defined completely herein.

2. INSTALLATION FEATURES

2.1. Dimensions.--An installation drawing of the engine is shown in Figure A-1. The dimensions are noted both for 70°F and also at maximum operating temperature. Detailed engine drawings shall be provided the airframe contractor as they become available.

2.2. Weight.--The dry weight of the complete engine excluding instrumentation and excluding control intelligence pressure lines forward of the engine inlet shall not exceed 920 pounds. This weight also excludes any exterior shrouds and attachments therefore ducting diffuser bleed air aft, and excludes the weight of any insulation which may be required between the engine and the airframe.

3. PERFORMANCE CHARACTERISTICS

3.1. The ratings and curves shown are based upon the terms defined herein and Type RJ-1 fuel at its minimum heating value of 18,500 Btu/lb. The applicable fuel specification shall be MIL-F-25558B. The performance ratings are listed in Table A-I.

3.2. Performance at conditions other than the rating points is presented in Figures A-3 through A-23. This performance includes the effect of air bleed for cooling, leakage, and driving the air turbine fuel pump. Figure A-3 is acceleration performance with the variable exhaust nozzle in its maximum open position. Figures A-4 through A-12 are acceleration and climb performance wherein the exhaust nozzle throat area is variable as is the fuel-air ratio. Figures A-13 through A-15 are transition performance, acceleration to cruise. Figures A-16 through A-23 are cruise performance at specific engine inlet total temperatures.

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TABLE A-I

RATING TABLE

Condition	T_{t_2} (^oR)	W_a (pps)	W_f (pps)	T_E Absolute Exit Thrust (lbs)	Exit Specific Fuel Consumption lbs fuel/hr / lb exit thrust	P_{t_2} Minimum (psia)	Fuel Temperature (^oF)	Engine Inlet Minimum Fuel Pressure	Remarks
gnition	767.	128.4	--	--	--	--	0° to 250°	--	Ignition will occur 0.1 sec after manual command
Maximum Power Operation	767.	128.4	7.43	22,360	1.149	26.00	0° to 250°	--	
Maximum Power Operation	1635.	51.33	1.93 - 2.04	9,847	.708	28.51	0° to 250°	--	
Cruise Exit sfc	1635.	48.8	1.01 - 1.68	Figure A-2	Figure A-2	28.3	0° to 250°	--	

3.3. A reference engine mission curve is shown in Figure A-24. This curve is related to an assumed diffuser performance shown in Addendum I.

3.4. Ignition and Reignition.--The engine shall make consistent successful starts in the operating envelope shown in Figure A-25. In the event the engine blows out, reignition shall be obtained within ___ seconds after the transient causing blowout has ceased and reignition manual command is received anywhere within the envelope shown in Figure A-25.

3.5. Cold Flow Engine Operation.- The engine shall perform as shown in Figure A-26 during cold flow operation.

4. ENVIRONMENT

4.1. Limits Imposed on Engine.-

4.1.1. Inlet.- The engine shall deliver the performance specified in Section 3.2 at the ranges of engine inlet air flow and total temperature shown in Figures A-27 and A-28. The engine inlet air flow shall have maximum allowable deviations from the mean inlet total pressure and mean Mach number of ± 5 percent and/or ± 20 percent, respectively, over the central 95 percent of the inlet area. There shall be no reverse flow anywhere over the engine inlet area.

4.1.2. Rate of Change of Inlet Conditions.- The performance specified in Section 3.2 shall be obtained with a maximum rate of change of inlet conditions not in excess of 150 percent of those in the reference mission curves of Section 3.3.

4.1.3. External Cooling Air Requirements.- To be determined.

4.2. Limits, Engine Generated.-

4.2.1. Limiting Zone Temperature and Heat Rejection.- To be determined.

4.2.2. Vibration.- To be determined

5. PILOT CONTROL PROCEDURES

5.1. Pilot precedures for operating and controlling the engine system are described in Figure A-29 and Table II. Figure A-29 schematically shows the discrete throttle positions which select the mode of engine system operation and also shows the ranges of throttle positions for operating modes wherein thrust modulation is available. Table A-II describes the operational sequences of all controlled variables of the engine system as correlated with typical mission requirements.

TABLE A-II

ENGINE OPERATING SEQUENCE

	Operational Conditions	Remarks	Thrust Throttle Position	Exit Nozzle Switch Position	Exit Nozzle Position	#1 Fuel Injector Flow	#2 Fuel Injector Flow	Ignition Switch	Nominal Engine Inlet Air Temperature (°F)	Nominal Combustion Chamber Gas Temperature (°F)
1.	Take Off & Carry	1. Exit Nozzle Locked Closed	Off	Closed*	Closed (Locked)	Off	Off	Off	--	--
2.	PreStart Sequence	1. Energize Panel 2. Open Inlet Cover	Off	Ignition	Open	Off	Off	Off	--	--
		3. Start Boost Pumps 4. Open Engine Fuel Supply Valve 5. Exit Nozzle Controlled to Ignition Position by Shock Position Control (S.P.C.) 6. Start Inlet	Ready	Ignition	Open	Off	Off	Off	--	--
3.	Engine Start	1. Activate Ignition Switch (By-pass Door Closed)	Ready	Ignition	Controlled Position for Super-critical inlet	Off	Off	On	200 to 300	200 to 300
		2. Place Throttle in Min. Thrust Position	Min. Thrust	Ignition	Controlled Position for Super-critical inlet	On (Ig. F/A Sched.)	Off	Off	200 to 300	1500
		3. Place Exit Nozzle Switch in Thrust Position After Ignition (Bypass Door Closed)	Min. Thrust	Thrust	Controlled Position for Critical Inlet	On (Max. Th. F/A Schedule)	Off	Off	200 to 300	1500
4.	Maximum Thrust for Power Burst Check & Separation	1. Exit Nozzle Opens Full 2. Bypass Door Opens as Required	Max. Thrust	Thrust	Full Open	On (Max. Th. F/A Schedule)	On (T_{t_5} Demand Control)	Off	200 to 300	3200
5.	Acceleration	1. F/A Scheduled for Max. T_5	Max. Thrust	Thrust	Varies from Full Open to Closed Position with Flight Speed to Maintain Critical Operation	On (Max. Th. F/A Schedule)	On (T_{t_5} Demand Control)	Off	200 to 1175	3200

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TABLE A-II (Continued)

Operational Condition	Remarks	Thrust Throttle Position	Exit Nozzle Switch Position	Exit Nozzle Position	#1 Fuel Injector Flow	#2 Fuel Injector Flow	Ignition Switch	Nominal Engine Inlet Air Temperature (°F)	Nominal Combustion Chamber Gas Temperature (°F)
	2. Exit Nozzle Area Maintains Critical Pressure Recovery. 3. By-pass Doors open as required to avoid shock expulsion. Closed at intermed. Mach number								
6. Cruise	1. By-pass Doors Closed, Open only during severe transient conditions. 2. $\frac{\Delta CF}{\Delta MO}$ Increased for stable speed control 3. Cruise Thrust Varied as req'd by throttle position range.	Cruise	Thrust	Controlled to Maintain Critical Pressure Recovery	$\frac{\text{On}}{T_{t_5}}$ Control Bias	Off	Off	1175	2450 to 3100
7. Descent	1. Engine system fuel cooled during descent on min. thrust operation. 2. By-pass door closed	Min. Thrust	Thrust	Controlled to Maintain Critical Pressure Recovery	$\frac{\text{On}}{\text{(F/A}}$ Sched.)	Off	Off	1175	2000
8. Emergency Thrust		Emerg. Thrust	Thrust	Controlled to Maintain Critical Pressure Recovery	$\frac{\text{On}}{\text{(F/A}}$ Sched.)	On (T_{t_5} Demand Sched.)	Off		3300 to 3450
9. Engine Re-start	1. At all Mach numbers 2. Inlet must be started prior to ignition.	Min. Thrust	Ignition	Controlled for Super-critical inlet.	On (Ignition F/A Sched.)	Off	On	200 to 1175	1300 to 2000
10. Engine Shut Down	1. Place throttle in ready position to shut down engine 2. Close (lock) exit nozzle prior to shut off of engine fuel supply.	Off	Closed	Closed (Locked)	Off	Off	Off	--	--

6. ENGINE CONTROLS AND FUEL SYSTEM

6.1. General Description.- The power control system shall consist of an engine bleed air turbine fuel pump system, a fuel flow regulating system, a variable exhaust nozzle actuating and control system, an electrical ignition system, a mechanical manual input control system, a pneumatic signal sensing system, and appropriate instrumentation readouts. The power control system shall be packaged within the engine installation envelope with the exception of the pneumatic signal sensing system which shall be located at suitable positions in the engine and air induction system. The power control system shall require no power supplies external to the engine other than the low pressure fuel supply to the engine, pneumatic flows and pressures from the pneumatic signal sensing system, and electrical power.

6.2. Operating Description.- The power control system shall automatically control engine fuel flows, engine exhaust nozzle position, and induction system pressure recoveries so as to establish and maintain the desired mode of engine operation as determined by manual input selection. The controllable modes of engine operation shall be as shown in Figure A-29 and Table A-II as itemized herein.

6.2.1. Thrust Control Inputs.-

6.2.1.1. Off Position.-

6.2.1.2. Ready Position.-

6.2.1.3. Minimum Thrust Positions.-

6.2.1.4. Cruise Thrust Position(s).-

6.2.1.5. Maximum Thrust Position(s).-

6.2.1.6. Emergency Thrust Position(s).-

6.2.2. Exit Nozzle Control Inputs.-

6.2.2.1. Ignition Position.-

6.2.2.2. Thrust Position.-

6.2.2.3. Closed Position.-

6.3. Performance Power Control System.- The power control system shall perform with characteristics and accuracies so as to provide the following engine and induction system performance.

6.3.1. Engine Performance.- The power control system shall control engine variables so that the engine shall deliver the performance specified in Sections 3.1, 3.2, and 3.4.

6.3.1.1. Cruise Thrust Gain.- The power control system shall provide a thrust change to Mach number change characteristic as shown in Figure A-30 during cruise operation.

6.3.2. Diffuser Performance.- The power control system shall limit and maintain diffuser pressure recovery in accordance with Figure A-31 during engine and diffuser operating conditions wherein control of pressure recovery is required, provided pneumatic signal intelligence to the engine is in accordance with paragraph 6.4.1.

6.4. Environment.- The engine control system performance levels described herein are applicable to typical operating conditions of an isolated engine with regard to engine and control inputs. In cases of multiple engine application, the stated performance levels shall be provided if no steady state interaction of diffuser and engines subsystems exists and if possible dynamic interaction exists in the phugoid mode only.

6.4.1. Pneumatic Signals.- The power control system shall provide the performance specified in Section 6.3 provided that pneumatic signals accurately describe characteristics such as percent of diffuser mean pressure recovery less than the diffuser can deliver with inlet started conditions. The diffuser pneumatic signals shall provide the minimum pressure levels, gains, as shown in Figure A-32.

6.4.1.1. Location of Diffuser Pneumatic Signal Probes.- Probe configurations, location, connecting plumbing, and their signal characteristics shall be mutually determined.

6.4.1.2. Icing Conditions.- The induction system design shall provide suitable protection against icing conditions to the engine power control signal probes and pneumatic intakes during engine nonoperating periods. No protection shall be required during engine operation.

6.4.1.3. Pneumatic Contamination.- The control system shall incorporate suitable filters for pneumatic signal inputs. Limits of contamination contents of the air from the pneumatic signal sensing system probes shall be determined.

6.4.2. Rate of Change of Conditions.- The power control system shall perform satisfactorily under the rate of change of engine inlet conditions specified in Section 4.3. The engine control system shall not be required to maintain diffuser inlet started operation during those transients which could cause diffuser inlet shock expulsion.

6.4.3. Fuel Sypply.- The power control system shall operate satisfactorily when supplied with fuel at the engine inlet having temperatures ranging from 0°F to +450°F and fuel densities within the ranges presented in Figure A-33.

6.4.3.1. Fuel Pressure.- Fuel shall be supplied at the engine inlet with maximum pressures in accordance with Figure A-34 and with pressure variations within the limits shown by Figure A-35.

6.4.3.2. Fuel Temperature Time Reference.- Fuel supply temperature as shown in Figure A-36 shall be used as the reference for all qualifying testing procedures.

6.4.3.3. Fuel Contamination.- The engine shall perform satisfactorily when supplied with contaminated fuel. The extent and consistency of fuel contamination shall be determined.

6.4.4. Fuel Leakage.- There shall be no fuel leakage from the power control system except from ports and drain lines specifically provided for this purpose. Fuel leakage characteristics shall be as mutually agreed.

6.4.5. Fuel Resistance.- The materials and designs used in the power control system shall be satisfactory when tested with the fuel(s) specified in Section 3.1.

6.4.6. Electrical Power Supply.- An electrical power supply, external to the engine, shall be provided to the control system. It shall consist of a 250 watt, single phase, 110 volts, 400 cycle, intermittant supply. The time duration(s) requirements for the power supply shall be determined.

6.4.7. Electrical Interference.- Electrical interference from the power control system shall conform to the applicable portions of Specification MIL-1-6181B.

6.4.8. Static Exposure.- The control system shall operate satisfactorily subsequent to soaking periods at hot and/or cold ambient temperatures. Values of soaking times and temperatures shall be determined.

6.4.9. Lubrication.- No external source of lubrication shall be required.

6.5. Connections.-

6.5.1. Throttle Input Connections.- To be determined.

6.5.2. Indicators.- Signals describing engine inlet air temperature, engine exhaust gas temperature, and engine compartment overheat temperatures shall be provided.

6.5.3. Ground Check Provisions.- Provisions shall be made in the engine control system design for pneumatic hydraulic, and electrical connections and calibration adjustments required during ground check.

7. PFRT TEST

7.1. Engine Selection.- The engine with all self-contained equipment shall be subjected to the PFRT only after successful completion of an acceptance test as defined in Section 8.

7.2. Endurance Runs.-

7.2.1. Procedure.- The complete engine, including all controls and accessory devices, shall be installed in the test facility with sufficient instrumentation to determine test conditions and performance. Cooling shall be simulated and designed to maintain material temperatures at the maximum value anticipated in flight. During these tests, the power control system shall meter the fuel to the burner and control the exit nozzle area. Variation in power control settings to give desired engine operating conditions shall be made by a manual throttle control and by synthetic inputs which shall be utilized to simulate intelligence which is normally derived from sources external of the engine. Readout indicators as furnished shall be utilized.

7.2.2. Tests.- The endurance test shall consist of four simulated reference trajectory runs. The trajectories shall be simulated as closely as the test facility capabilities allow in terms of engine inlet air flow and temperature as defined in Figure A-24.

7.2.3. Performance.- The calibration and tolerances of the throttle position at the engine and the functional operation and tolerances of the readout indicators shall be demonstrated during the following power traverses: minimum and maximum acceleration powers, minimum cruise power, and maximum cruise power. Engine cruise specific fuel consumption shall be measured frequently during the reference trajectory runs and shall increase continuously no more than 5 percent form the initial cruise phase of the first mission to the final cruise phase of the fourth mission.

7.2.4. Inspection Procedure.- Subsequent to the fourth simulated trajectory run, the engine shall be completely disassembled and each inspected dimensionally. No part shall have deformed to the extent that it would be capable of causing power failure. Details of this inspection shall be determined.

7.3 Component Test.-

7.3.1. Selection of engine control and fuel system components for PFRT shall be predicated on prior successful completion of an Acceptance Test as defined in Section 8.

7.3.2. Tests.- Bench tests simulating reference trajectories as defined in Section 7.2.2. shall be made. (The details shall be determined.)

7.3.2.1. Hot Fuel.-

7.3.2.2. Cold Fuel.-

7.3.2.3. Fuel Contamination.-

7.3.2.4. Soaking.-

7.3.3. Inspection Procedure.- To be determined.

8. ACCEPTANCE TEST

8.1. To be determined.

9. DELIVERY PROCEDURE

9.1. Following successful completion of the Acceptance Test and prior to delivery the engine shall be preserved for storage. (Detailed delivery procedure shall be determined.)

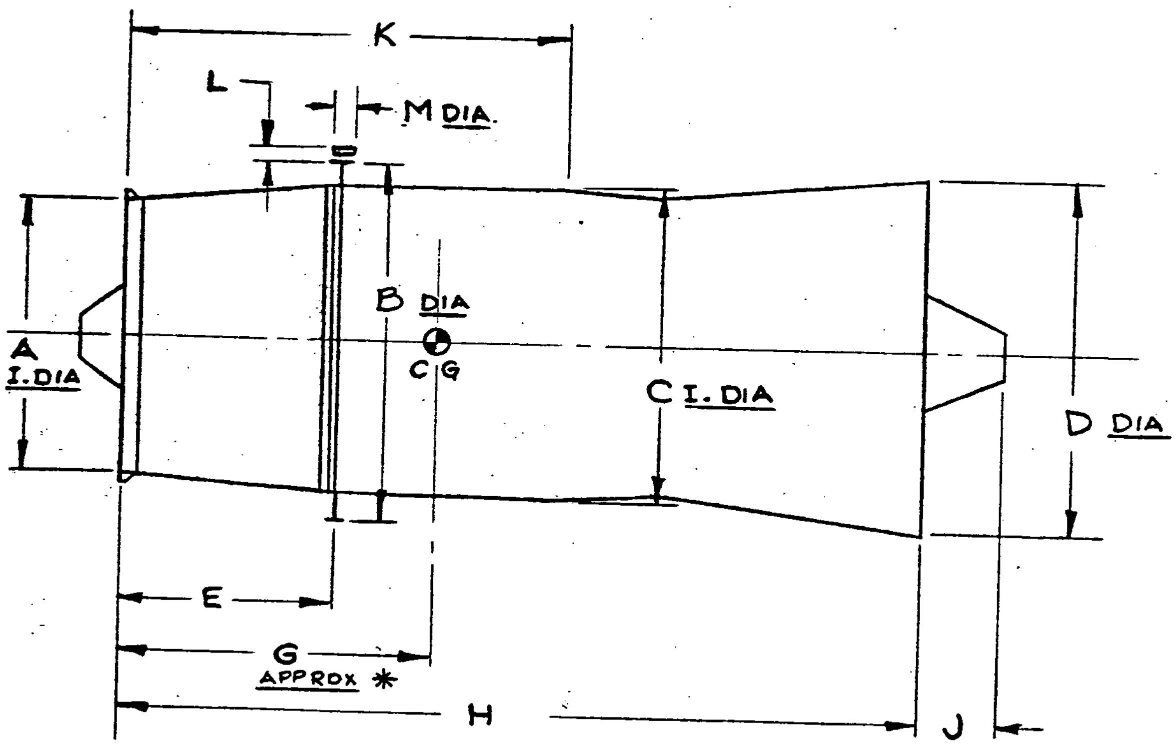
10. NOTES AND NOMENCLATURE

10.1 Nomenclature.-

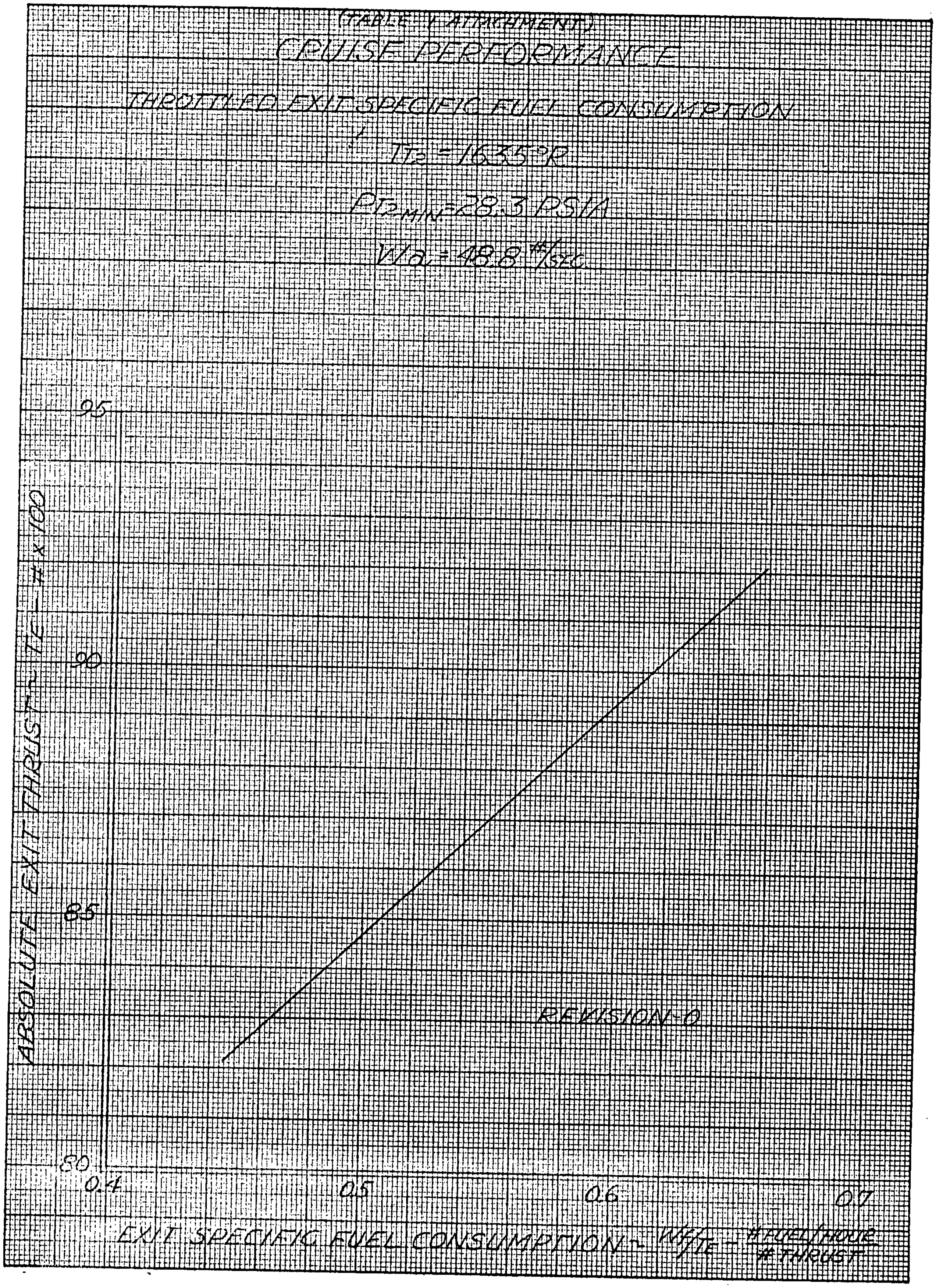
Symbol	Description	Unit
A	Flow area	sq in.
F/A	Ratio of fuel flow to air flow	none
M	Mach number	none
P	Pressure	lbs/sq in.
sfc	Exit specific fuel consumption	$\frac{\text{lbs fuel/hr}}{\text{lb absolute exit thrust}}$
T	Temperature	^{o}R or ^{o}F
t	Time	min or hr
T_E	Absolute exit thrust = $P_6 A_6 (1 + \gamma_6 M_6^2)$	lbs
W	Weight flow	pps
γ	Ratio of specific heats	

Subscripts	Description
a	Air
E	Exit
f	Fuel
t	Refers to stagnation conditions
Engine Stations	
2	Engine entrance station
3	Fictitious station at maximum combustor flow area (A_3 = 1001. sq in.)
4	Combustor exit station (A_4 = 1001 sq in.)
5	Geometric exit nozzle throat
6	Engine exit station

DIM.	COLD	HOT	
A	33.000	33.290	DIA'S
B	40.321	40.740	
C	37.713	38.141	
D	40.976	41.500	
E	24.262	24.500	LENGTH
* G		31.500	
H	91.226	92.250	
J	8.116	8.126	
K	48.029	48.500	
L	1.250		
M	2.000	2.008	



ENGINE INSTALLATION DRAWING


(TABLE I ATTACHMENT)
CRUISE PERFORMANCE
THROTTLED EXIT SPECIFIC FUEL CONSUMPTION
Tt2 = 1635°R
Pt2 MIN = 28.3 PSIA
Wa = 48.8 #/sec
ABSOLUTE EXIT THRUST ~ TE ~ # x 100
95
90
85
80
0.4
0.5
0.6
0.7
REVISION 0
EXIT SPECIFIC FUEL CONSUMPTION ~ Wf/TE ~ #FUEL/HOUR / #THRUST

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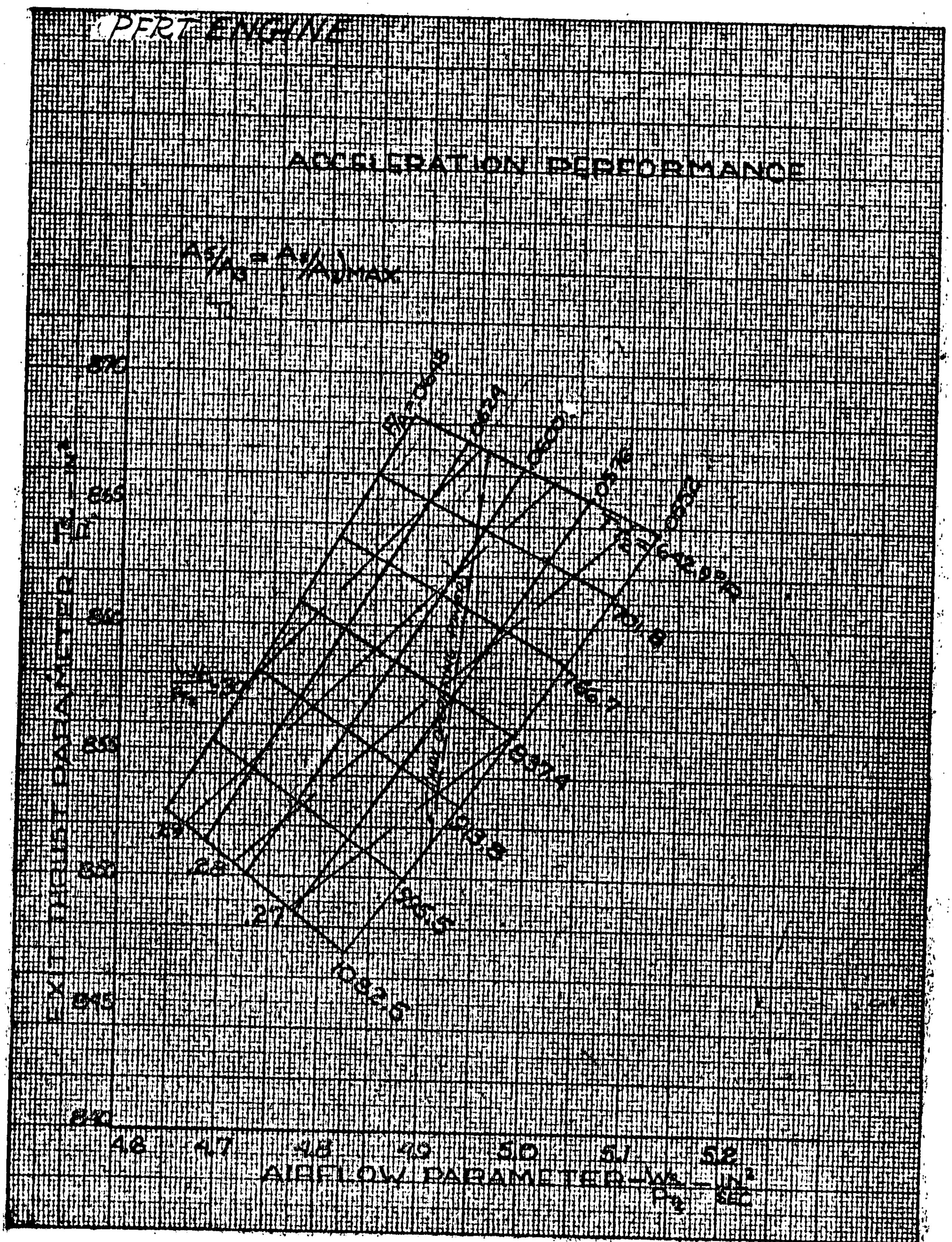
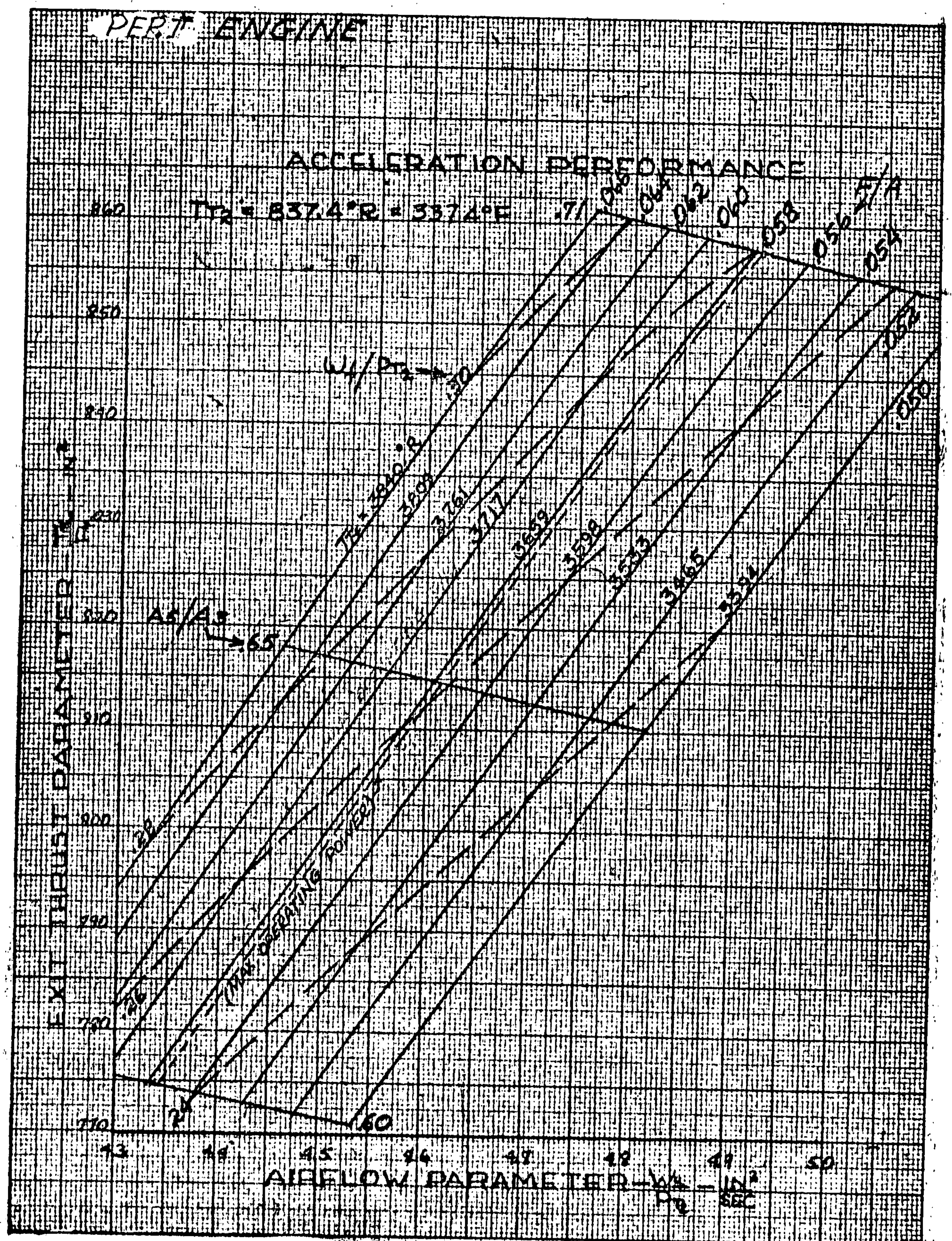

PERT ENGINE
ACCELERATION PERFORMANCE
.46 .47 .48 .49 .50 .51 .52
AIRFLOW PARAMETER
EXIT THRUST PARAMETER


PERT ENGINE
ACCELERATION PERFORMANCE
T_{T_2} = 837.4°R = 377.4°F
F/A
EXIT THRUST PARAMETER
AIRFLOW PARAMETER
43
44
45
46
47
48
49
50

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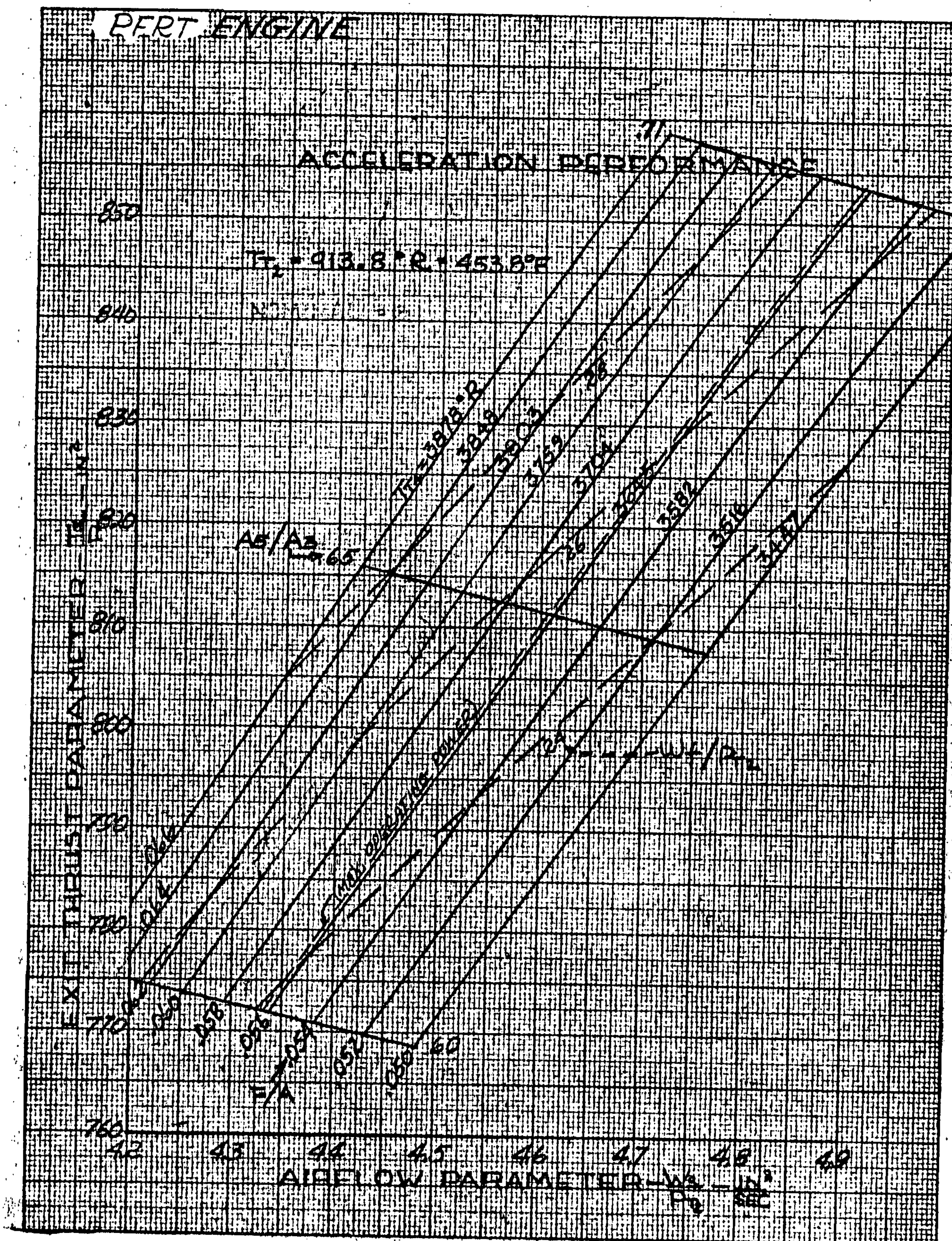
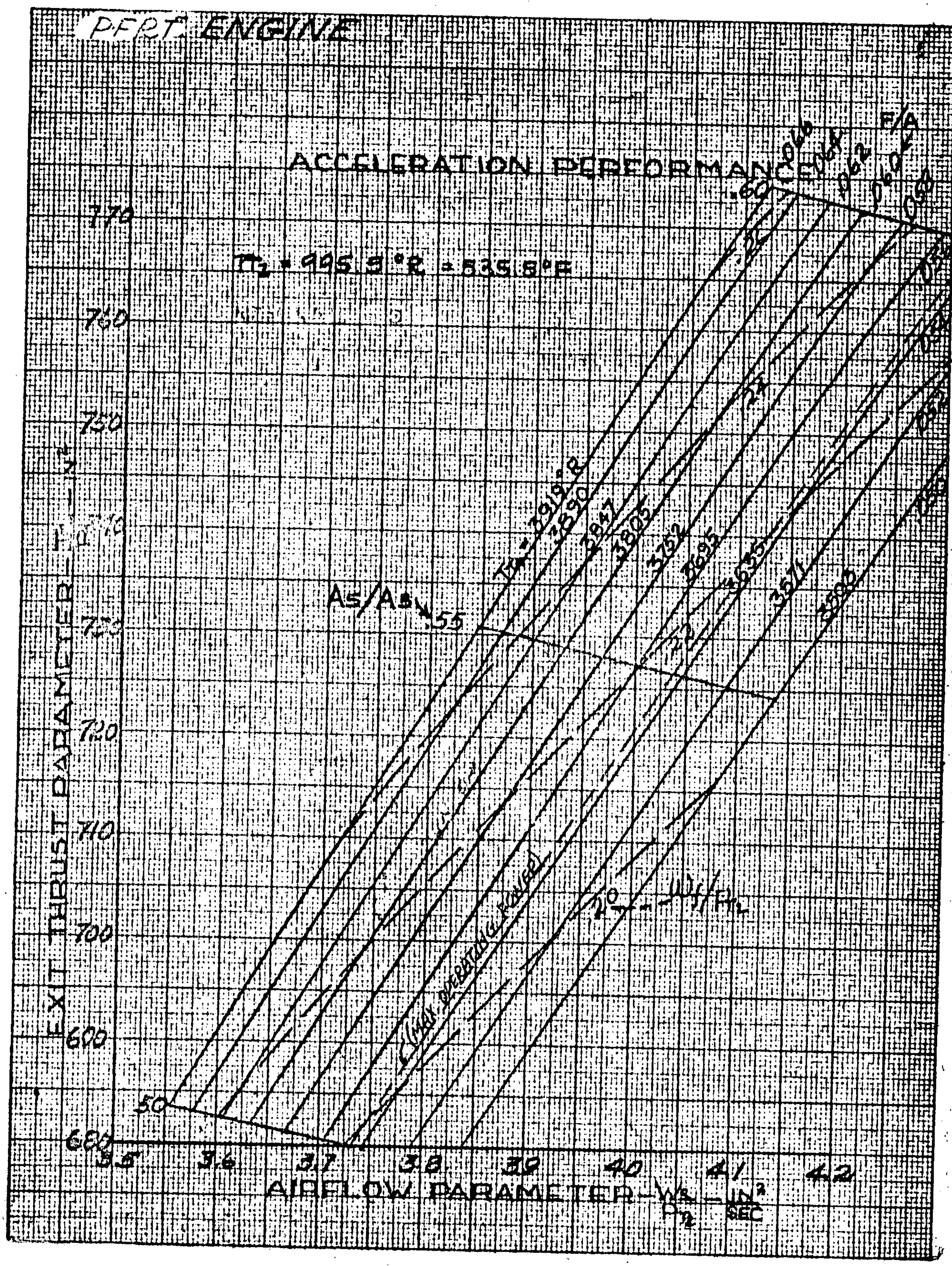
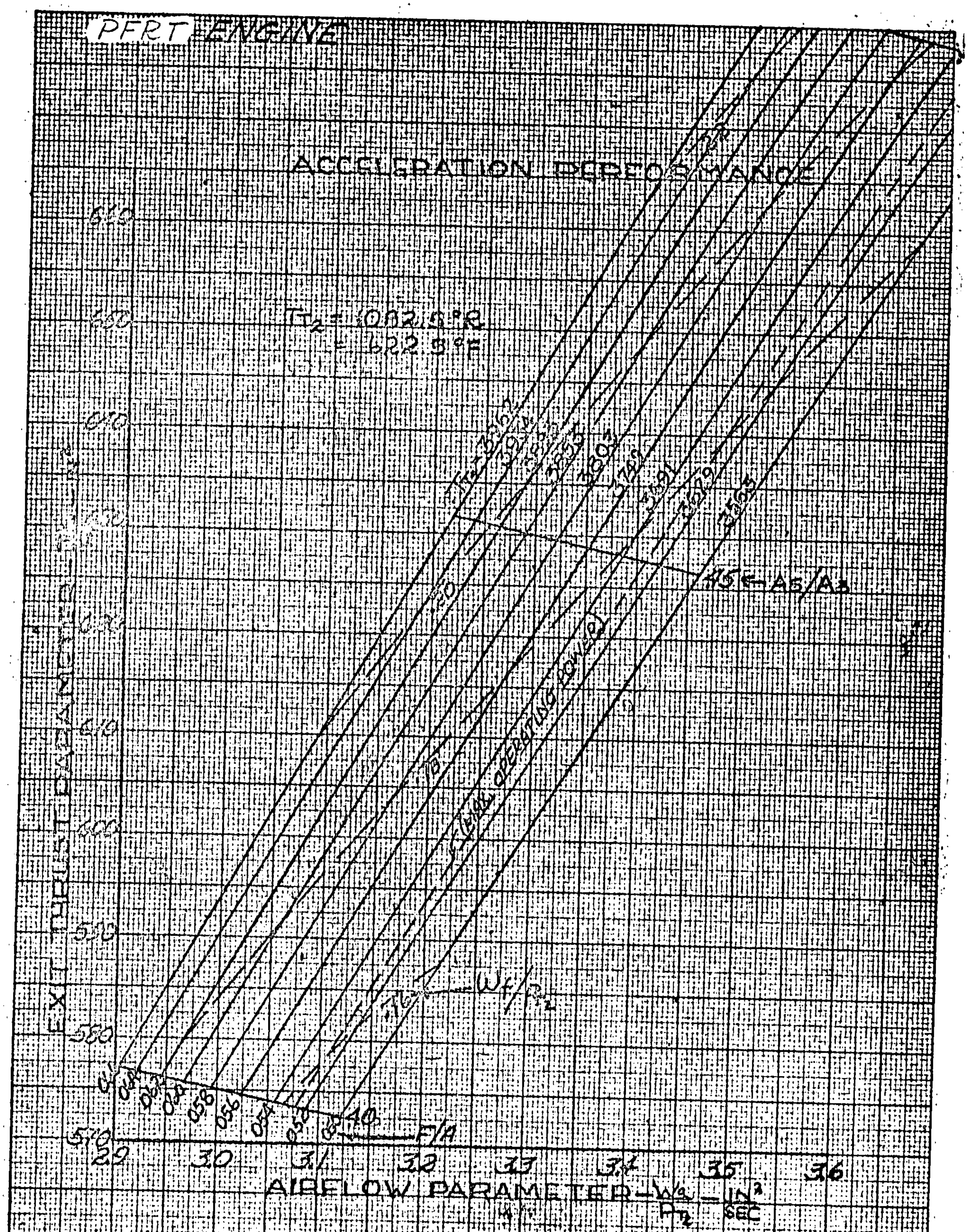
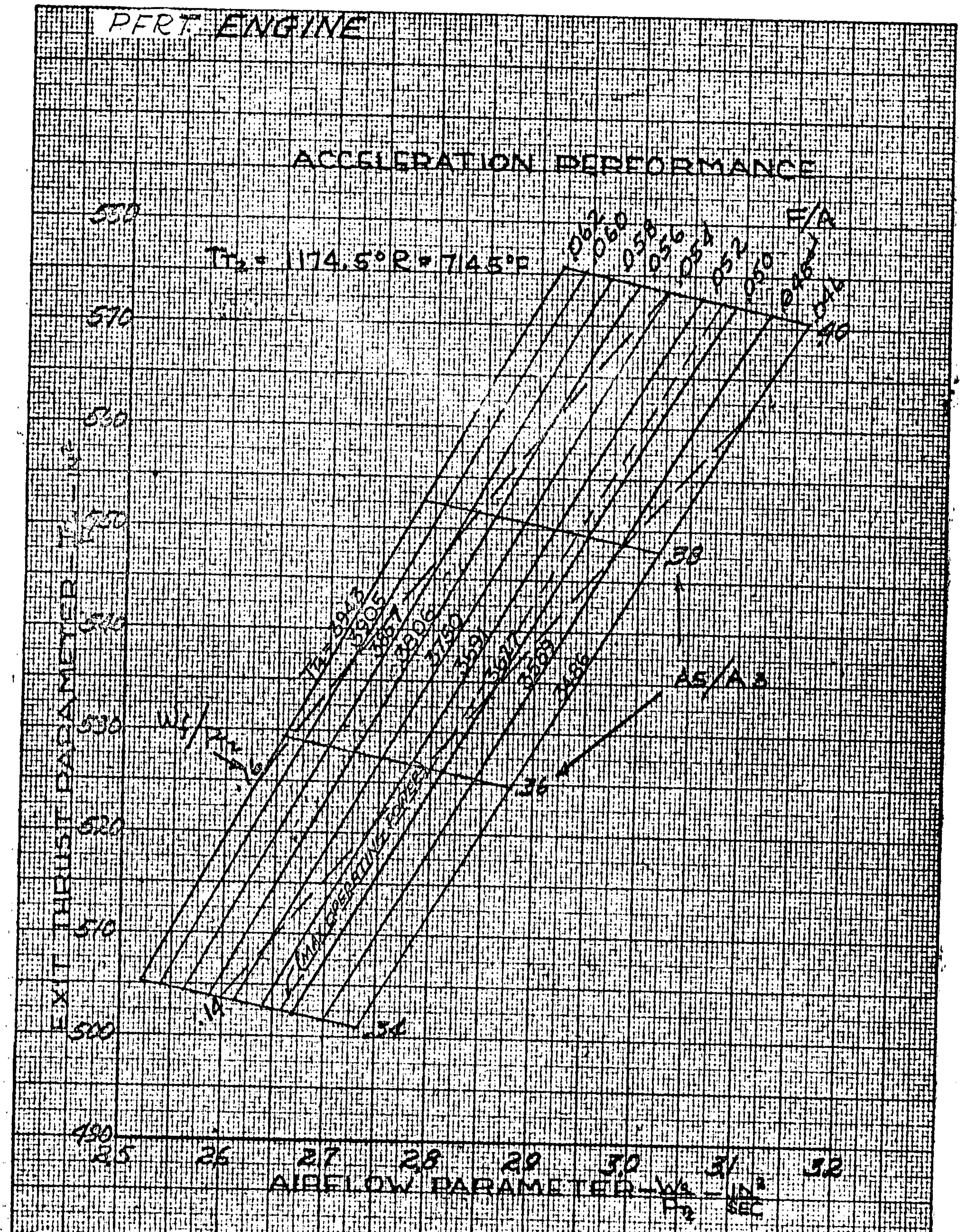
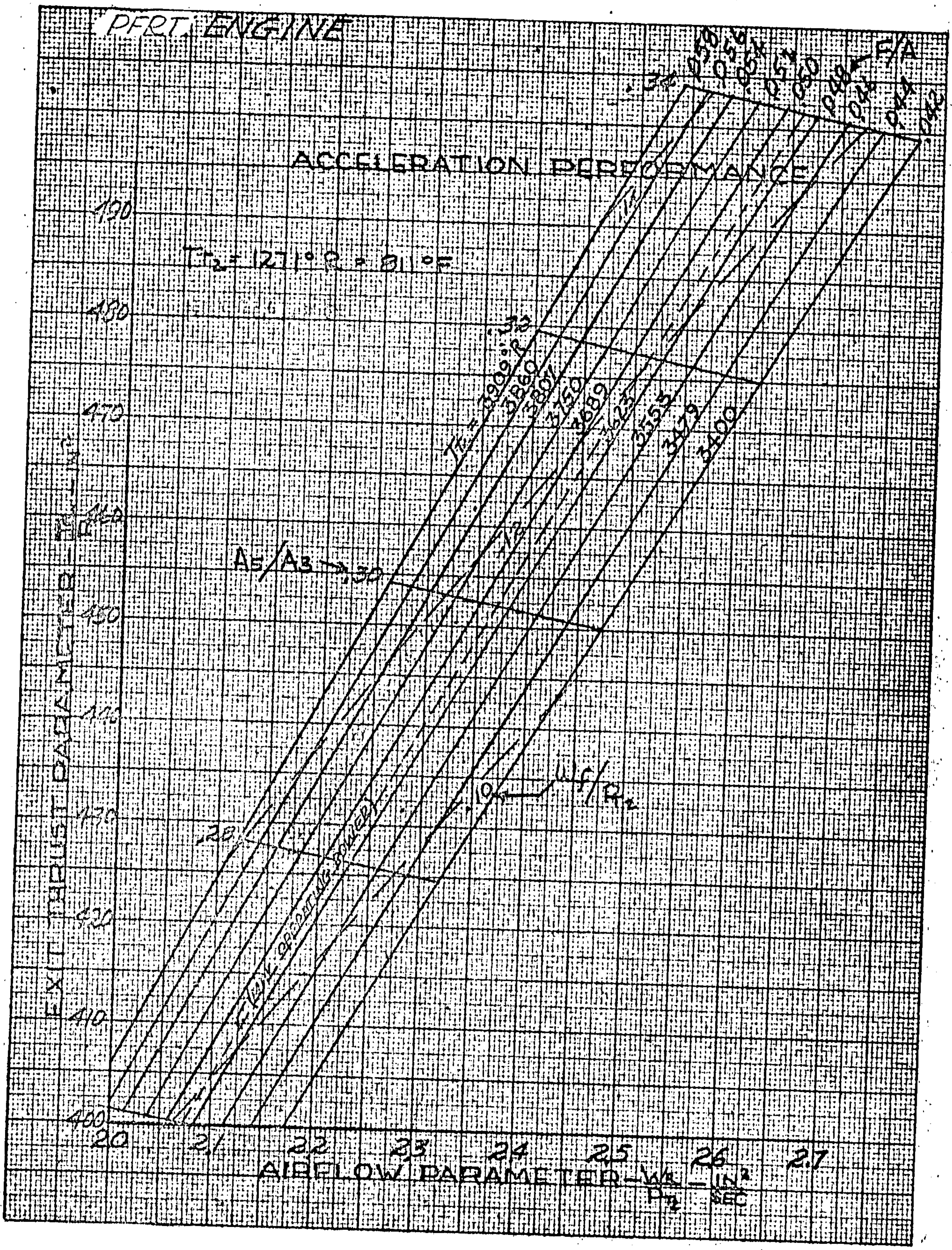
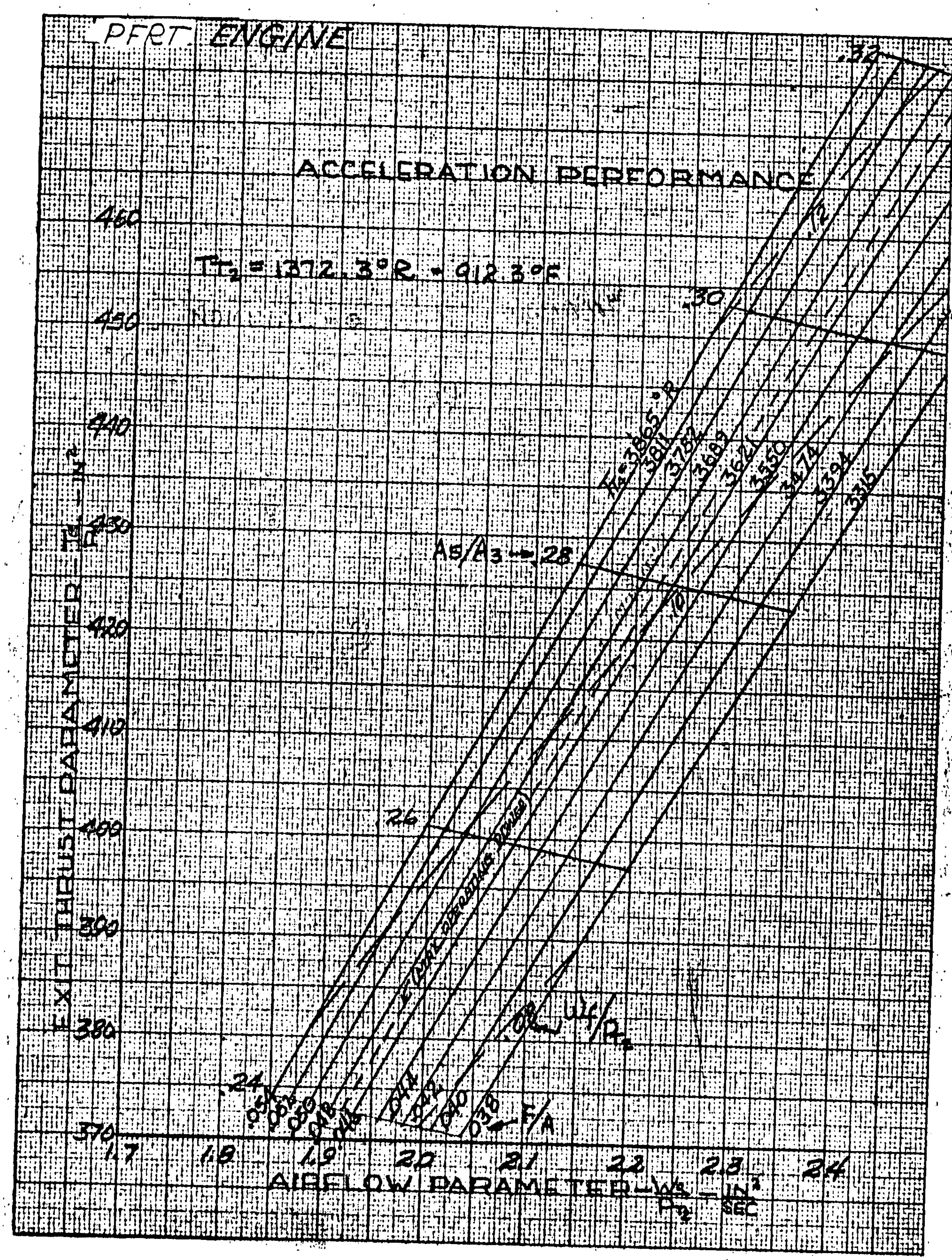

PERT ENGINE
ACCELERATION PERFORMANCE
T_{T_2} = 913.8°R = 453.8°F
A_5/A_3
.65
.60
F/A
AIRFLOW PARAMETER
EXIT THRUST PARAMETER
W_f/P_{T_2}
850
840
830
820
810
800
790
780
770
760
42
43
44
45
46
47
48
49


PERT ENGINE
ACCELERATION PERFORMANCE
F/A
T_{T_2} = 995.5°R = 535.5°F
As/A5 = .55
.60
.50
EXIT THRUST PARAMETER
AIRFLOW PARAMETER

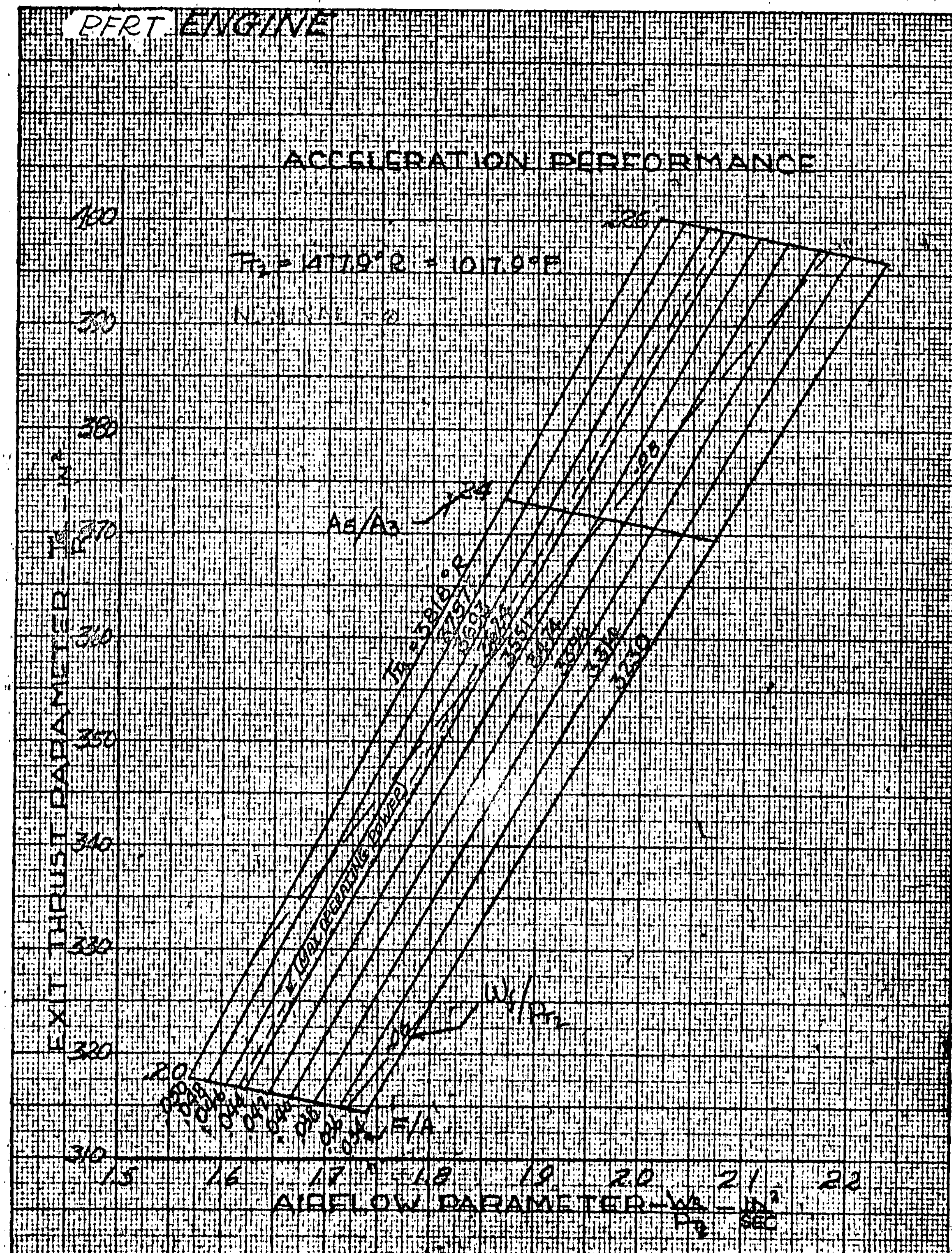

PFRT ENGINE
ACCELERATION PERFORMANCE
T_{T2} = 1082.5°R
= 622.5°F
45 ← A_5/A_3
W_f/P_2
F/A
AIRFLOW PARAMETER — $W_a\sqrt{}/P_2$ — IN²/SEC
29
30
31
32
33
34
35
36

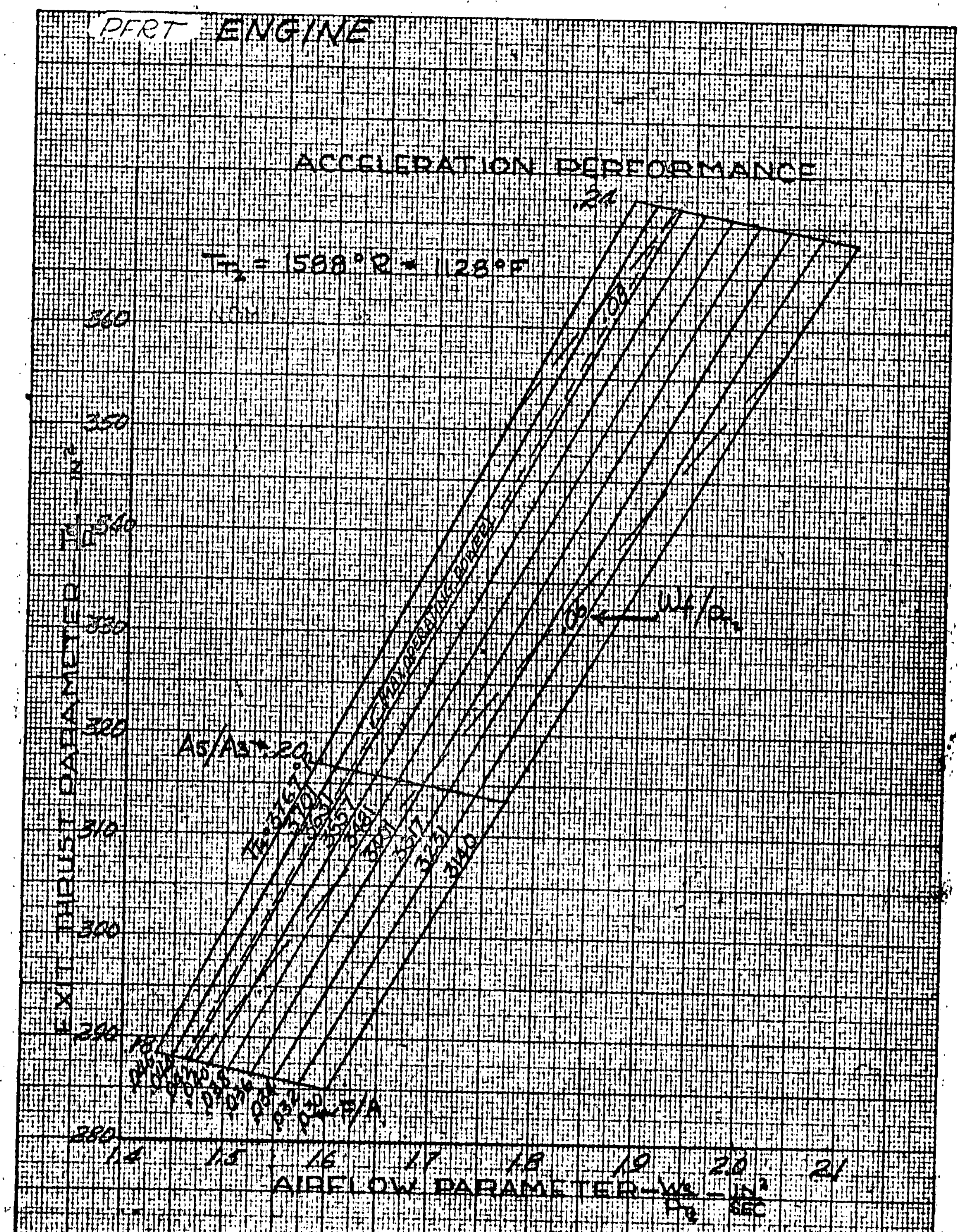

PERT ENGINE
ACCELERATION PERFORMANCE
F/A
.062 .060 .058 .056 .054 .052 .050 .048 .046
A5/A3
.40
.38
.36
.34
.14
EXIT THRUST PARAMETER
AIRFLOW PARAMETER
25 26 27 28 29 30 31 32
500 510 520 530 540 550 560 570 580
MAX OPERATING PRESS

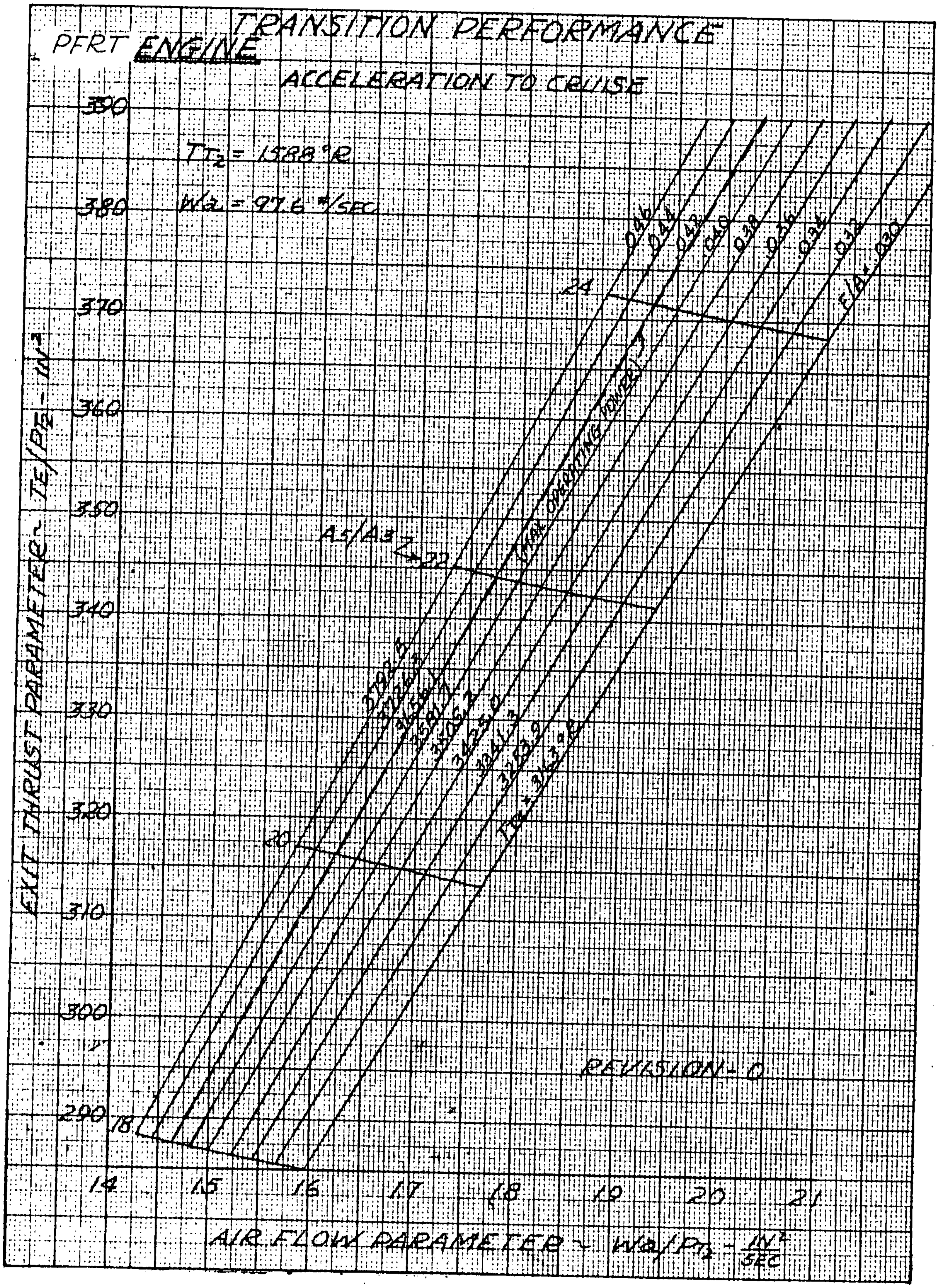

PERT. ENGINE
ACCELERATION PERFORMANCE
T_{T_2} = 1271°R = 811°F
F/A
.058
.056
.054
.052
.050
.048
.046
.044
.042
T_t = 3900°R
3860
3801
3750
3689
3625
3553
3479
3400
A_5/A_3 → .30
.32
.34
.28
W_f/P_2
.10
.12
.14
EXIT THRUST PARAMETER
400
410
420
430
440
450
460
470
480
490
20
21
22
23
24
25
26
27
AIRFLOW PARAMETER – $\frac{W_a}{P_2}$ – $\frac{IN^2}{SEC}$

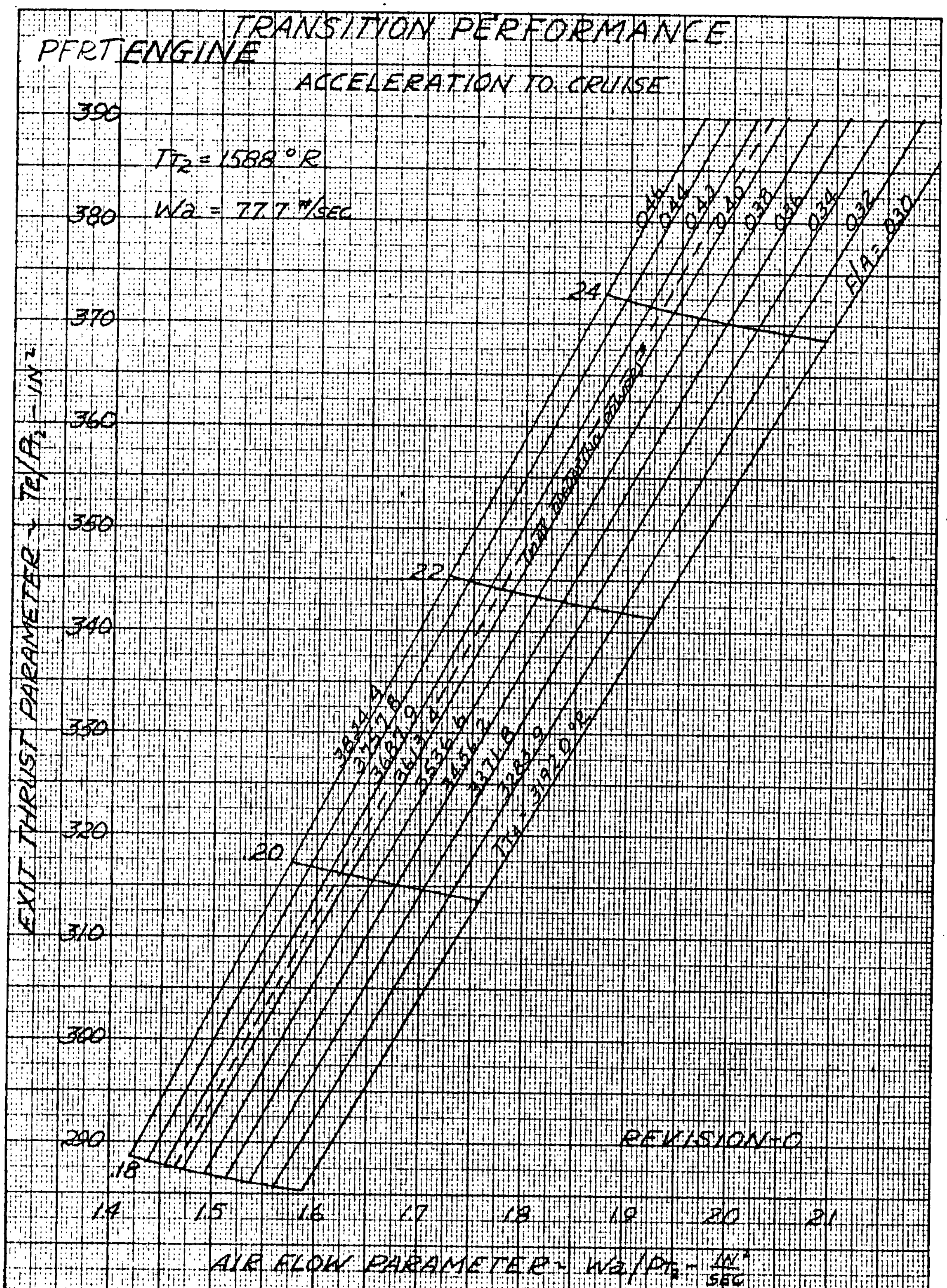

PFRT ENGINE
ACCELERATION PERFORMANCE
T_{T_2} = 1372.3°R = 912.3°F
EXIT THRUST PARAMETER
AIRFLOW PARAMETER
F/A
A5/A3 → .28
.24
.26
.30
.32
460
450
440
430
420
410
400
390
380
370
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4

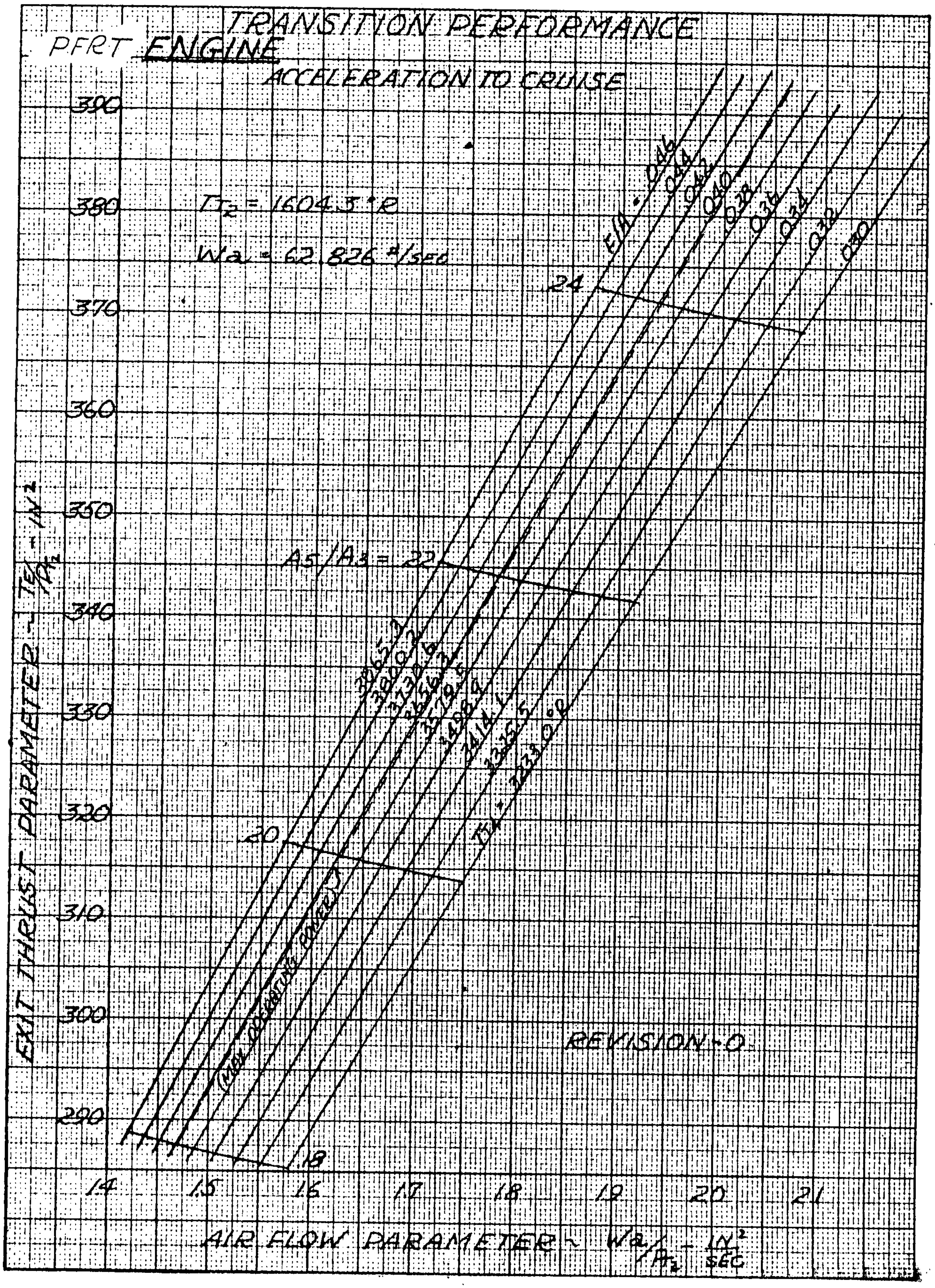
CONFIDENTIAL




PERT ENGINE
ACCELERATION PERFORMANCE
T_{T_2} = 1588°R = 1128°F
EXIT THRUST PARAMETER
A5/A3 → 2.0
2.4
F/A
W_f/P_{T_2}
360
350
340
330
320
310
300
290
280
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
AIRFLOW PARAMETER


TRANSITION PERFORMANCE
PFRT ENGINE
ACCELERATION TO CRUISE
T_{T_2} = 1588°R
Wa = 97.6 #/SEC
A5/A3 =
18
20
22
24
F/A = .030
.032
.034
.036
.038
.040
.042
.044
.046
MAX OPERATING POWER
TT4 = 3163°R
EXIT THRUST PARAMETER ~ TE/PT2 - IN²
AIR FLOW PARAMETER ~ Wa/PT3 - IN²/SEC
REVISION - D
290
300
310
320
330
340
350
360
370
380
390
14
15
16
17
18
19
20
21


TRANSITION PERFORMANCE
PFRT ENGINE
ACCELERATION TO CRUISE
$T_{T_2} = 1588\ °R$
$W_a = 77.7\ \#/SEC$
390
380
370
360
350
340
330
320
310
300
290
24
22
20
18
F/A = .030
.032
.034
.036
.038
.040
.041
.044
.046
T_{T_4} = 3192.0 °R
REVISION-0
14
15
16
17
18
19
20
21
EXIT THRUST PARAMETER ~ T_e/P_{T_2} ~ IN^2
AIR FLOW PARAMETER ~ W_a/P_{T_2} ~ $\frac{IN^2}{SEC}$


TRANSITION PERFORMANCE
PFRT ENGINE
ACCELERATION TO CRUISE
T_{T_2} = 1604.3 °R
Wa = 62.826 #/SEC
E/A = .046
.044
.042
.040
.038
.036
.034
.032
.030
24
A5/A3 = 22
20
18
3965.3
3800.2
3730.6
3656.3
3579.8
3498.4
3414.1
3326.5
TT4 = 3233.0 °R
(MAX OPERATING POWER)
REVISION - 0
390
380
370
360
350
340
330
320
310
300
290
14
15
16
17
18
19
20
21
EXIT THRUST PARAMETER ~ TE/PA2 ~ IN²
AIR FLOW PARAMETER ~ Wa/PA2 ~ IN²/SEC

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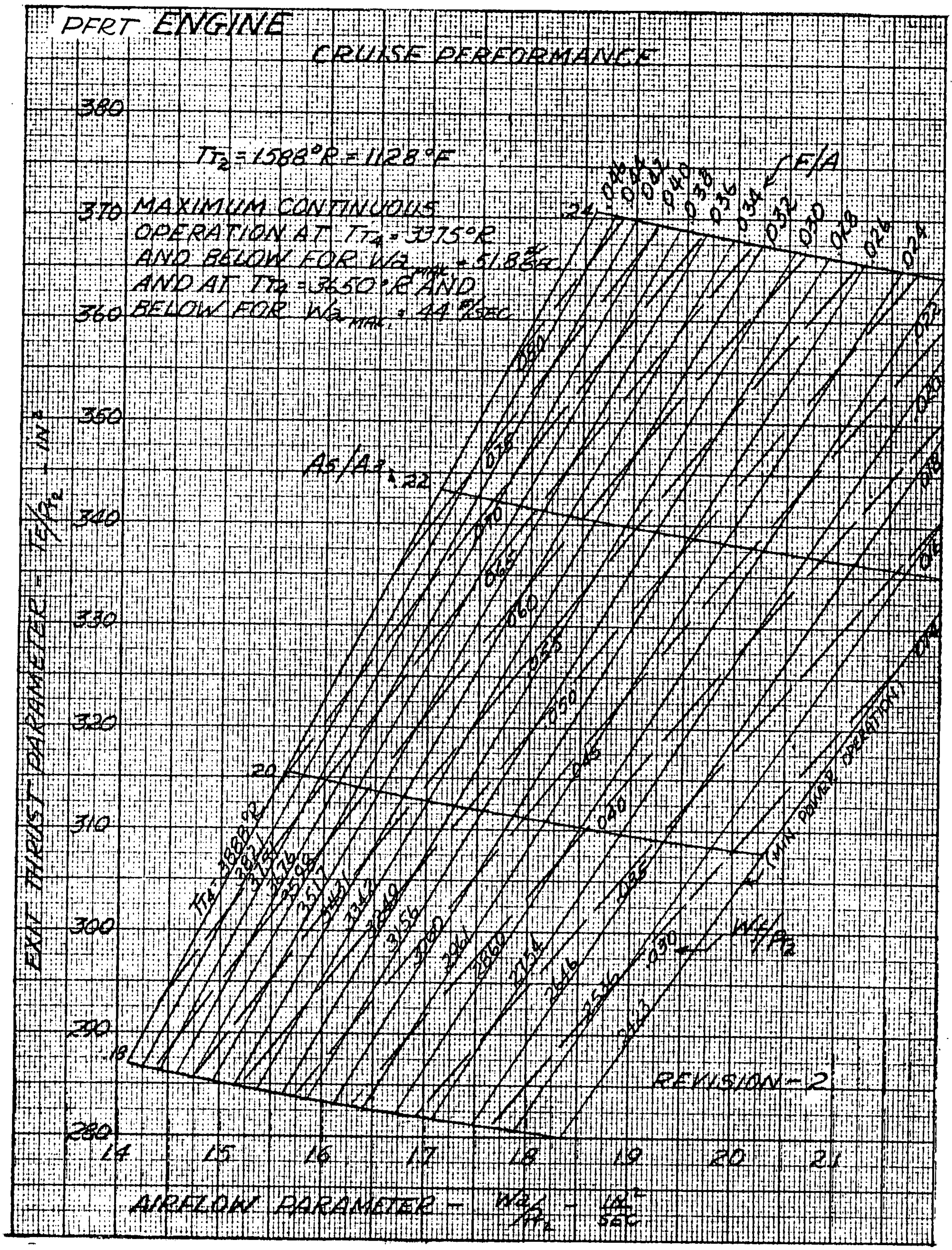
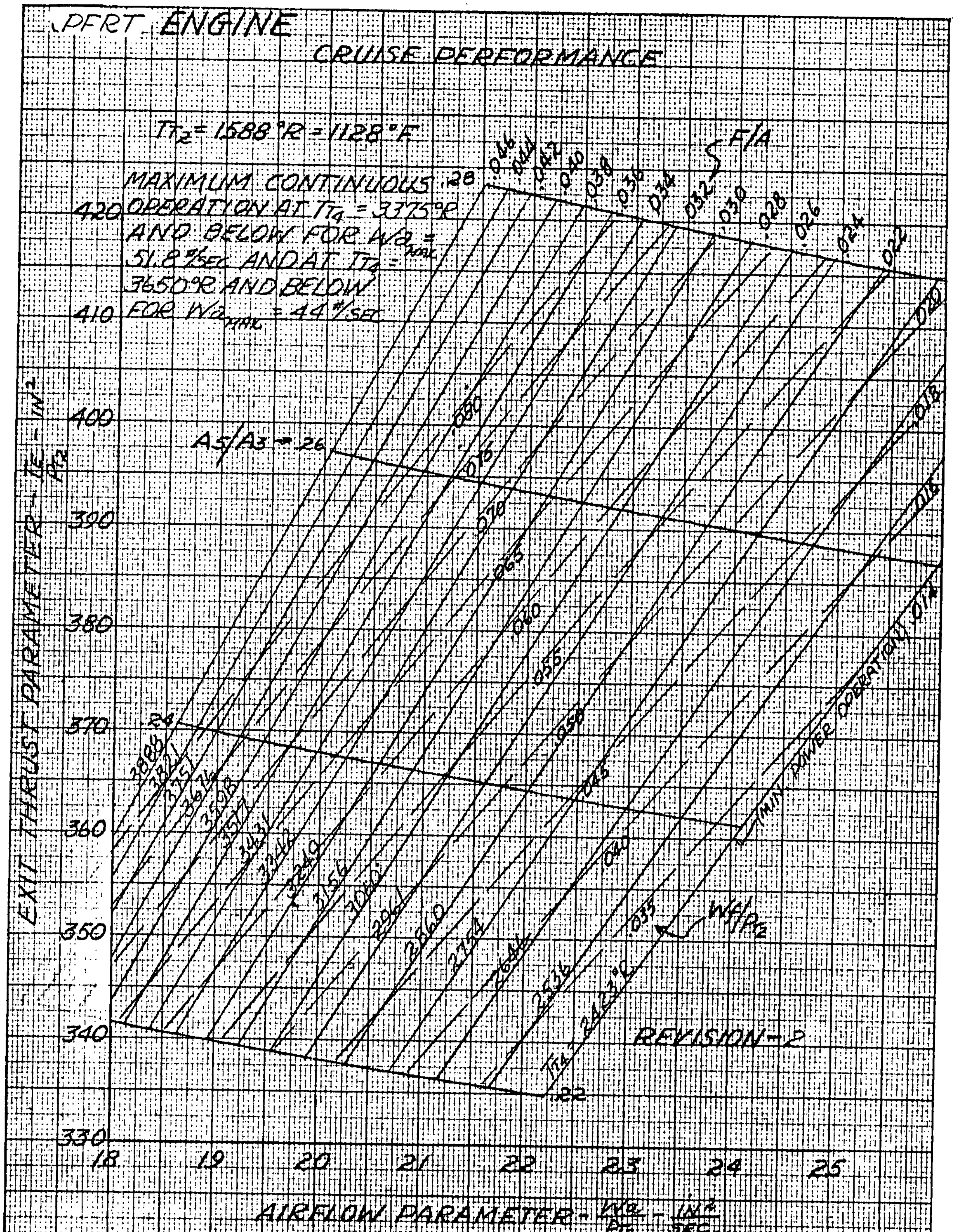
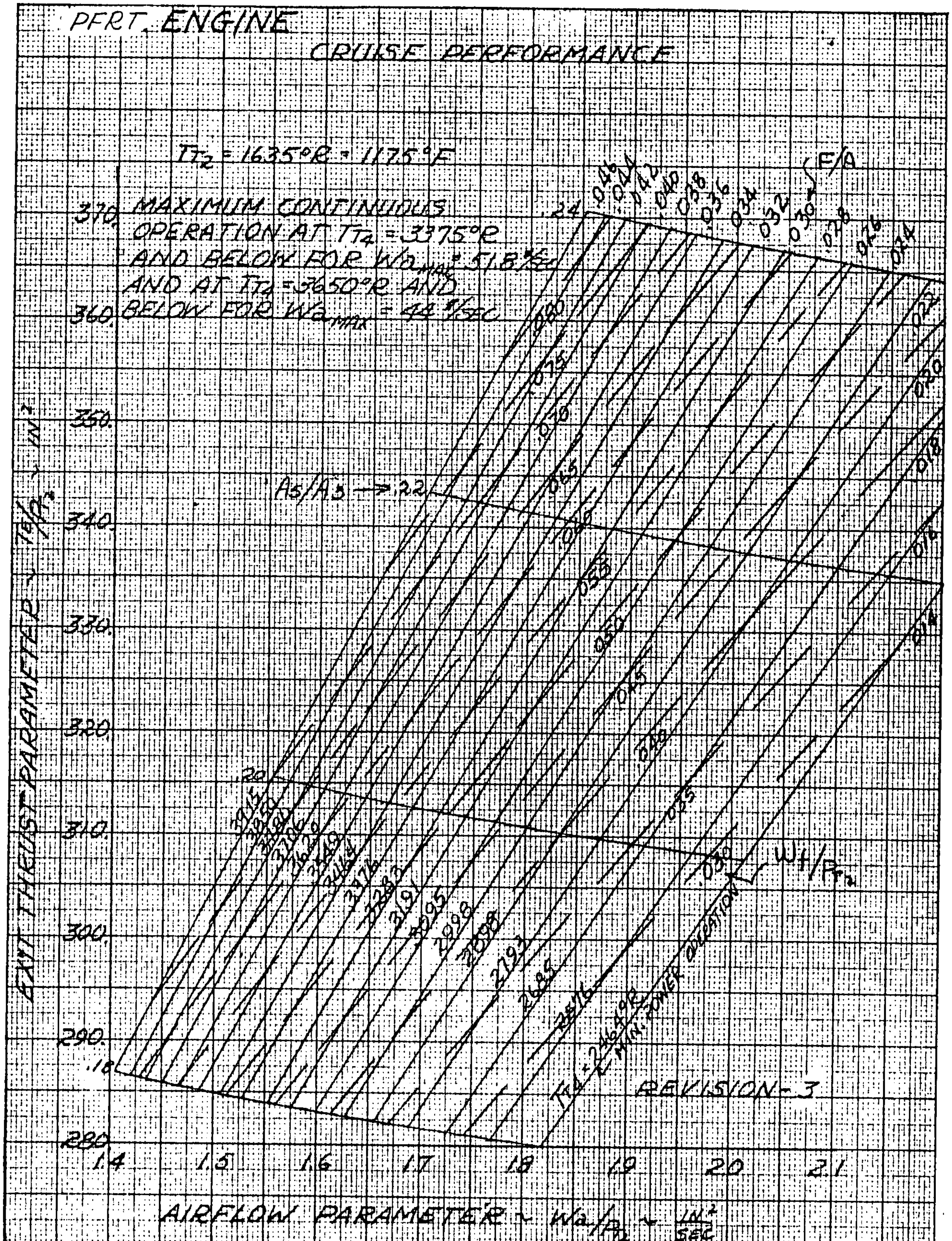
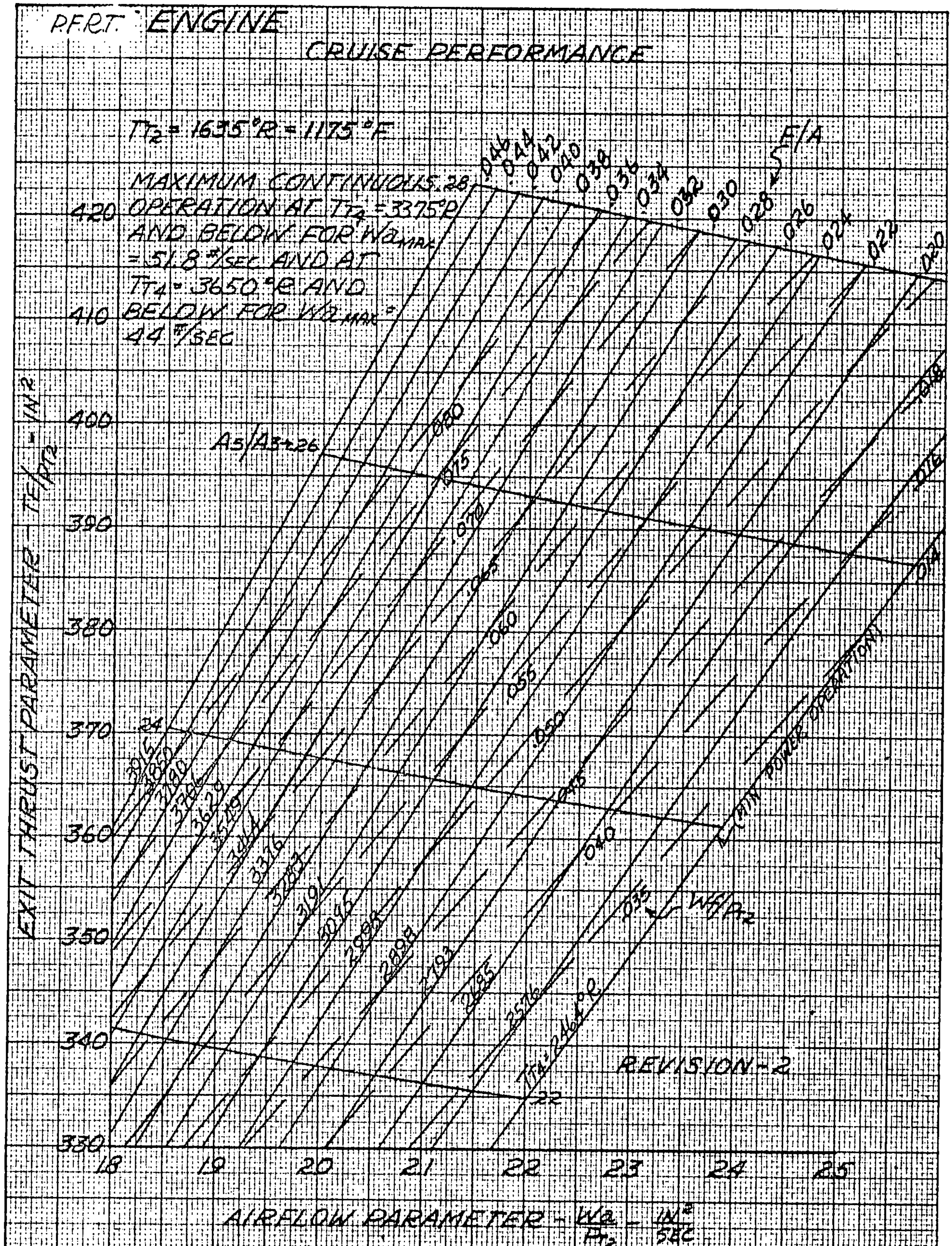
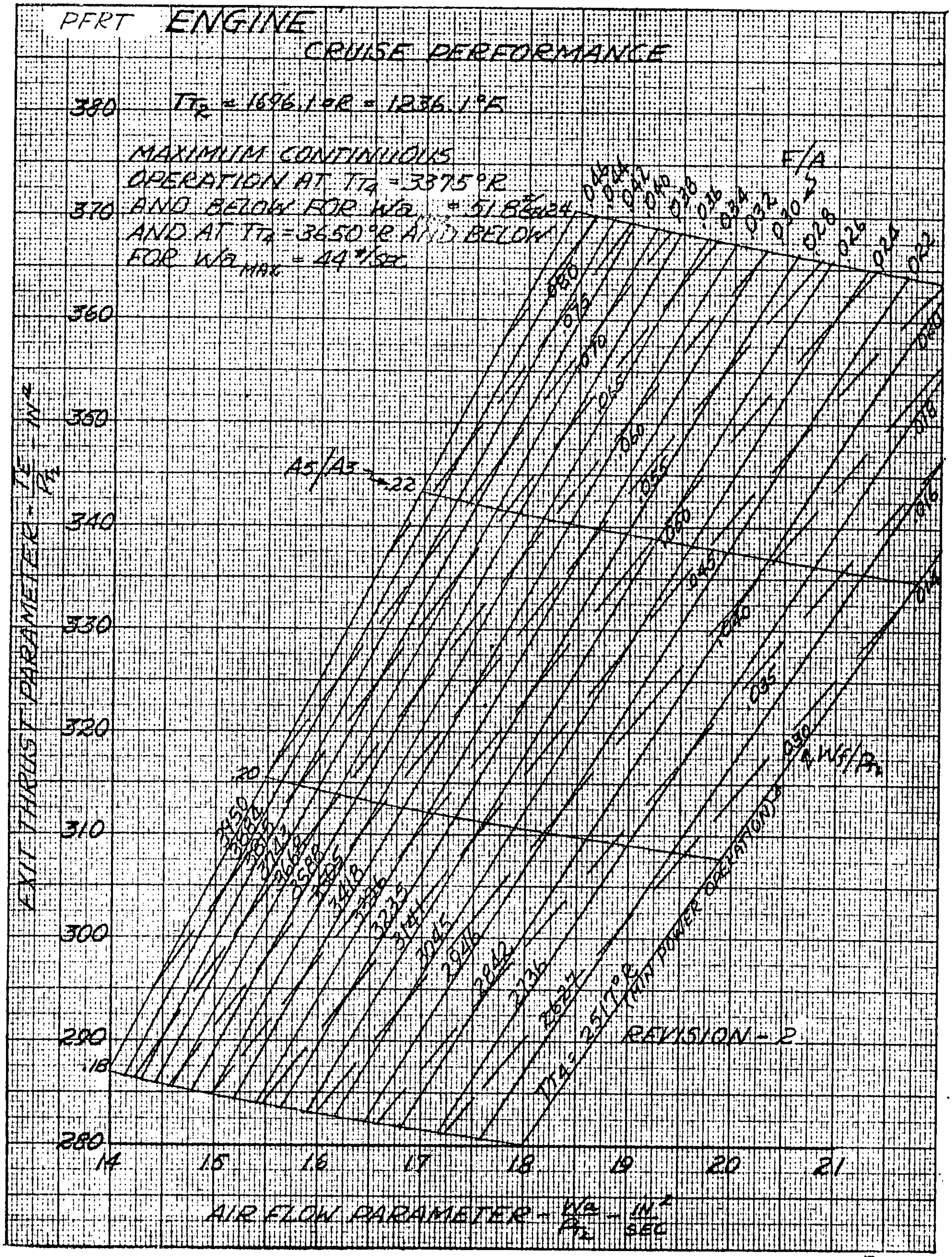
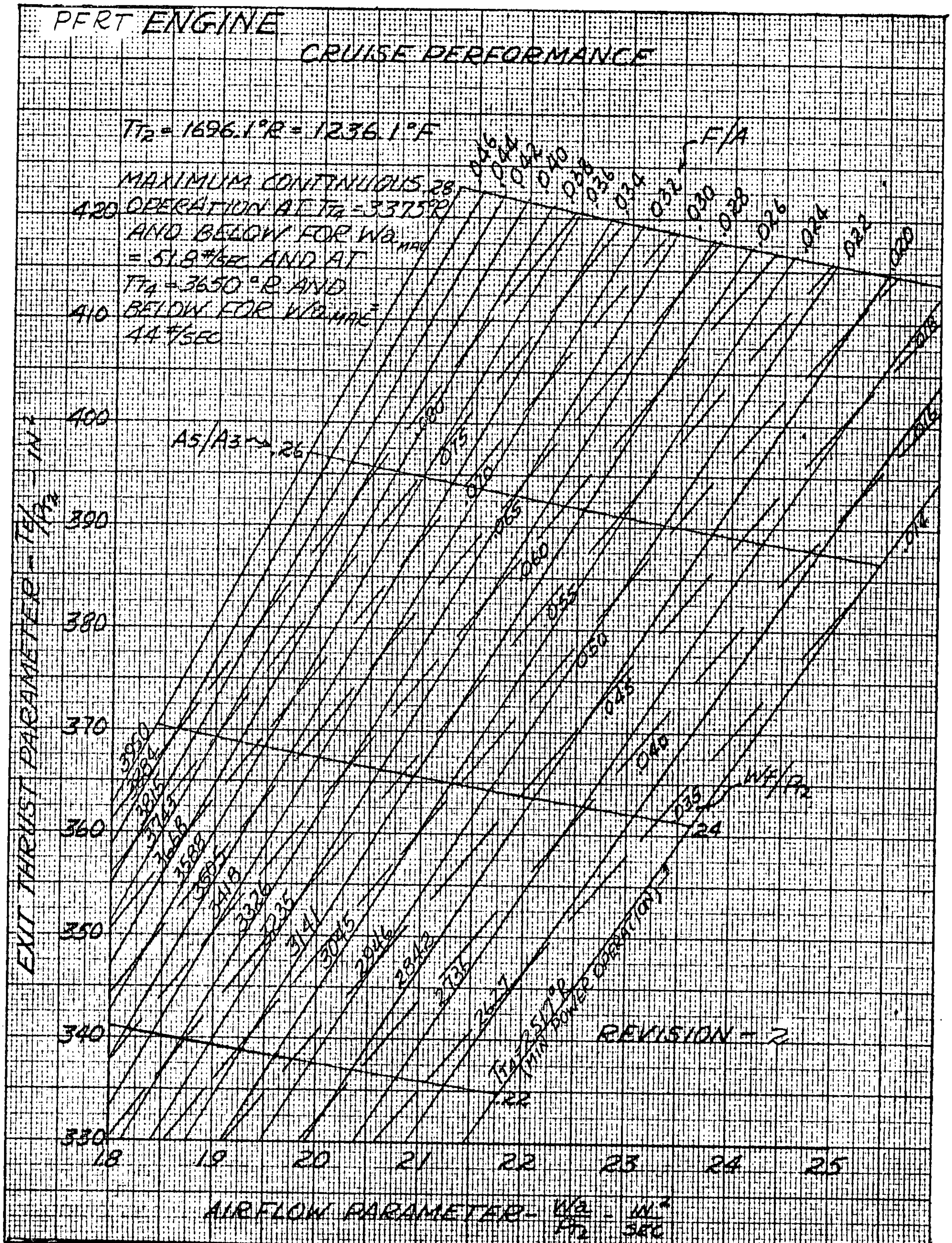

PFRT ENGINE
CRUISE PERFORMANCE
T_{T_2} = 1588°R = 1128°F
MAXIMUM CONTINUOUS
OPERATION AT T_{T_4} = 3375°R
AND BELOW FOR $W_{a\,max}$ = 51.8 #/SEC
AND AT T_{T_4} = 3650°R AND
BELOW FOR $W_{a\,max}$ = 44 #/SEC
F/A
A_5/A_2 = .22
.24
.20
.18
T_{T_4} = 3888°R
(MIN POWER OPERATION)
W_f/A_2
REVISION - 2
EXIT THRUST PARAMETER - T_E/δ_{T_2} - IN²
AIRFLOW PARAMETER - W_a/δ_{T_2} - LB/SEC
380
370
360
350
340
330
320
310
300
290
280
14
15
16
17
18
19
20
21

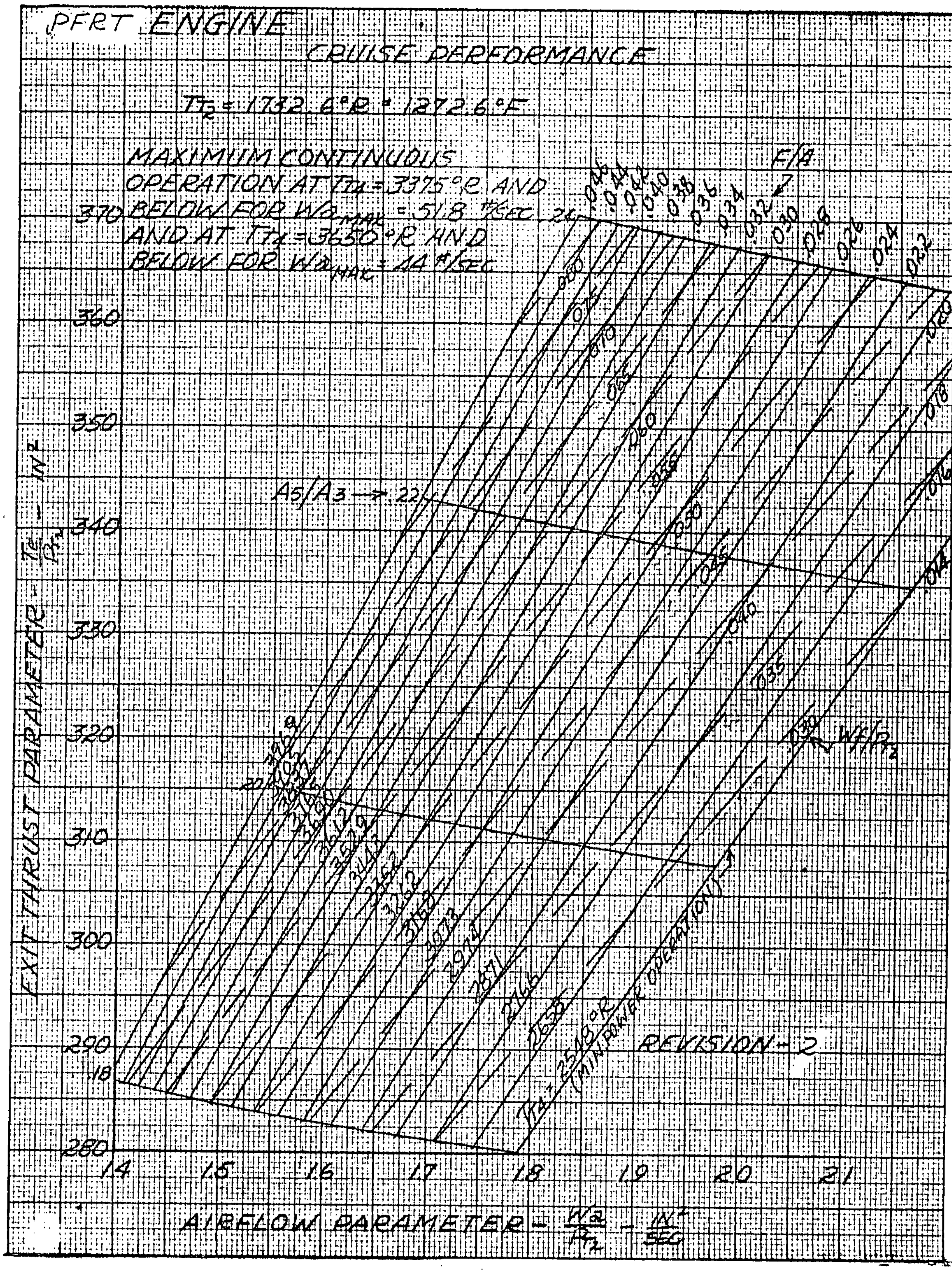

PERT ENGINE
CRUISE PERFORMANCE
T_{T_2} = 1588°R = 1128°F
MAXIMUM CONTINUOUS OPERATION AT T_{T_4} = 3375°R AND BELOW FOR $W_{a_{MAX}}$ = 51.8#/SEC AND AT T_{T_4} = 3650°R AND BELOW FOR $W_{a_{MAX}}$ = 44#/SEC
F/A
A5/A3 = .26
.28
.24
.22
MIN. POWER OPERATION
W_f/P_{T_2}
T_{T_4} - 2463°R
REVISION-2
EXIT THRUST PARAMETER - F_E/P_{T_2} - IN²
AIRFLOW PARAMETER - W_a/P_{T_2} - IN²/SEC

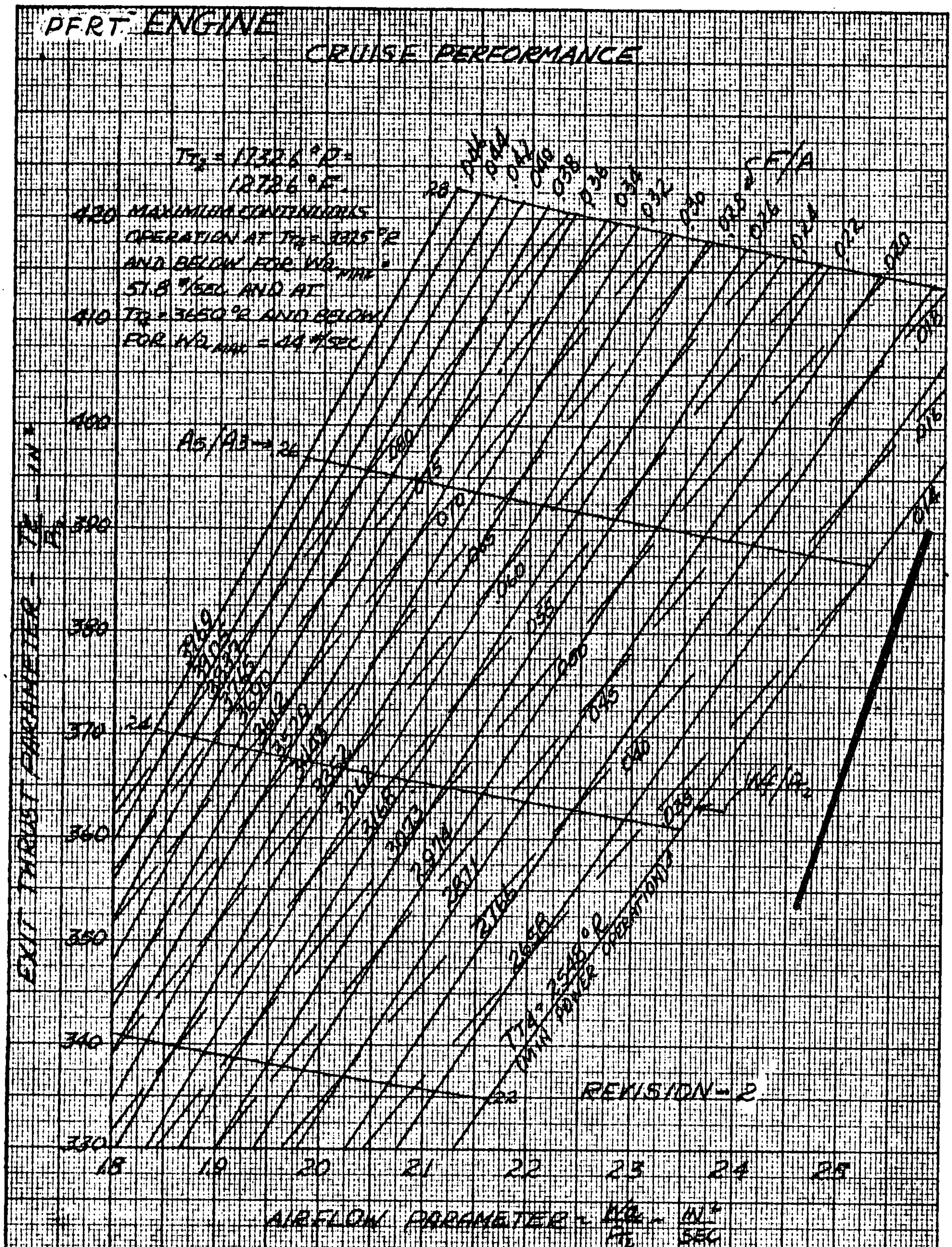

PFRT ENGINE
CRUISE PERFORMANCE
T_{T_2} = 1635°R = 1175°F
MAXIMUM CONTINUOUS OPERATION AT T_{T_4} = 3375°R AND BELOW FOR Wa_{max} = 51.8 #/SEC AND AT T_{T_4} = 3650°R AND BELOW FOR Wa_{max} = 44 #/SEC
F/A
A_5/A_3 → 2.2
Wf/P_{T_2}
T_{T_4} = 2464°R MIN. POWER OPERATION
REVISION - 3
EXIT THRUST PARAMETER ~ T_e/P_{T_2} ~ IN^2
AIRFLOW PARAMETER ~ Wa/P_{T_2} ~ $\frac{IN^2}{SEC}$

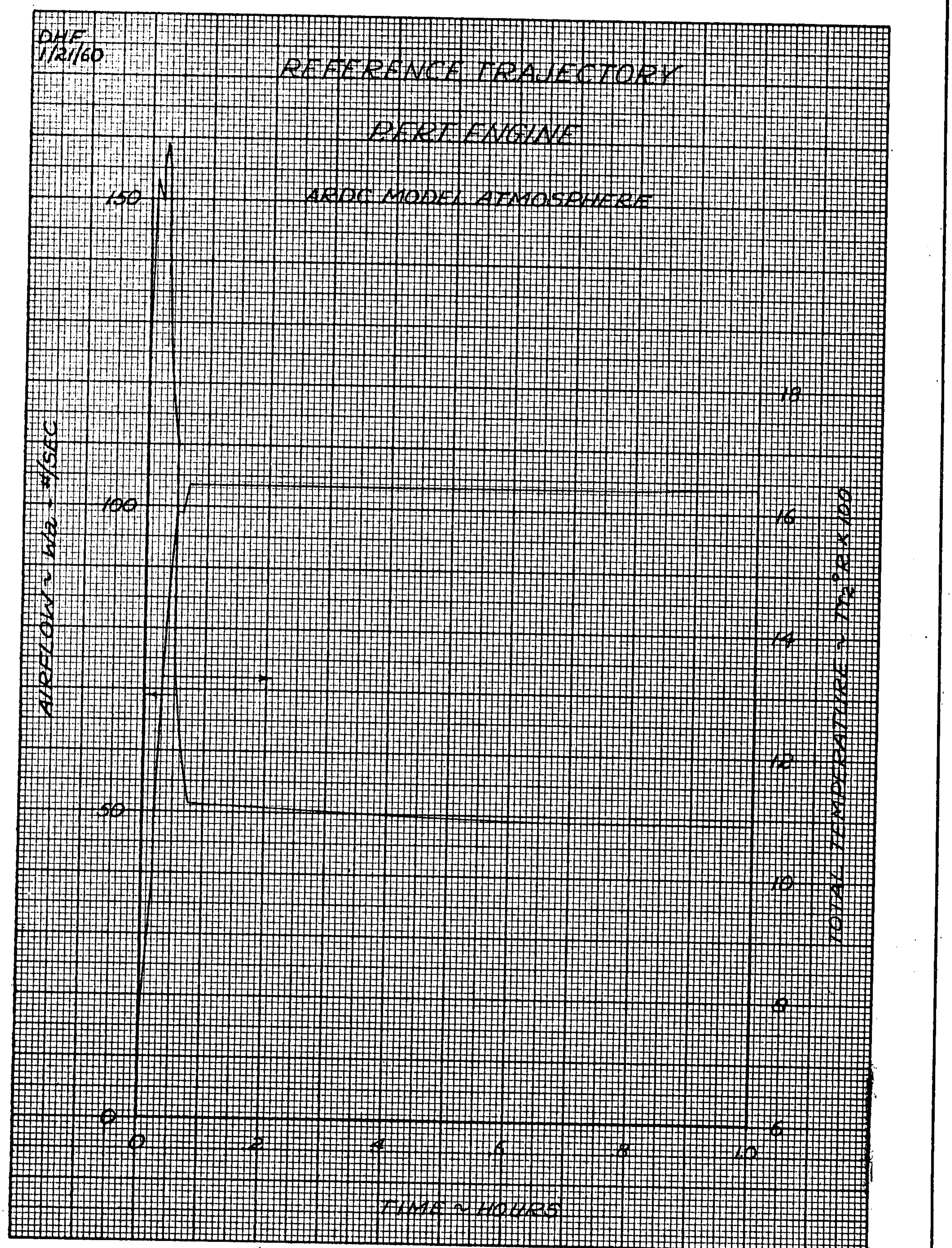

P.F.R.T. ENGINE
CRUISE PERFORMANCE
$T_{T_2} = 1635°R = 1175°F$
MAXIMUM CONTINUOUS .28 OPERATION AT T_{T_4} = 3375°R AND BELOW FOR $W_{a_{MAX}}$ = 51.8 #/SEC AND AT T_{T_4} = 3650°R AND BELOW FOR $W_{a_{MAX}}$ = 44 #/SEC
F/A
A5/A3 = .26
.24
.22
W_f/P_{T_2}
T_{T_4} = 2461°R
MIN POWER OPERATION
REVISION - 2
EXIT THRUST PARAMETER - T_E/P_{T_2} - IN²
AIRFLOW PARAMETER - $\frac{W_a}{P_{T_2}}$ - $\frac{IN^2}{SEC}$

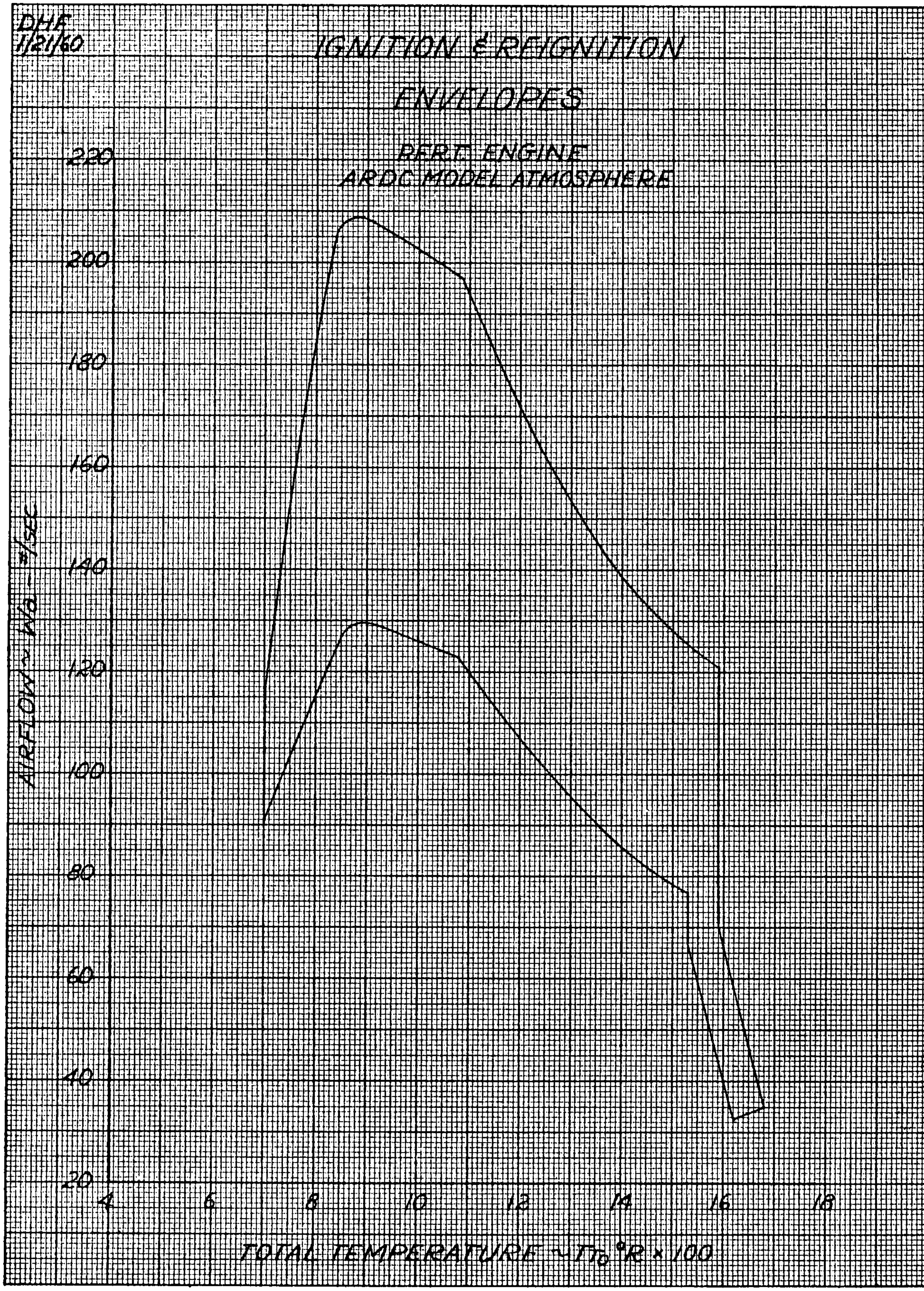

PFRT ENGINE
CRUISE PERFORMANCE
TT2 = 1696.1°R = 1236.1°F
MAXIMUM CONTINUOUS OPERATION AT TT4 = 3375°R AND BELOW FOR WA = 51.8#/SEC AND AT TT4 = 3650°R AND BELOW FOR WA MAX = 44#/SEC
F/A
A5/A3 → .22
.20
.18
WF/PT2
REVISION - 2
TT4 = 2511°R (MIN POWER OPERATION)
EXIT THRUST PARAMETER - FE/PT2 - IN²
AIR FLOW PARAMETER - WA/PT2 - IN²/SEC

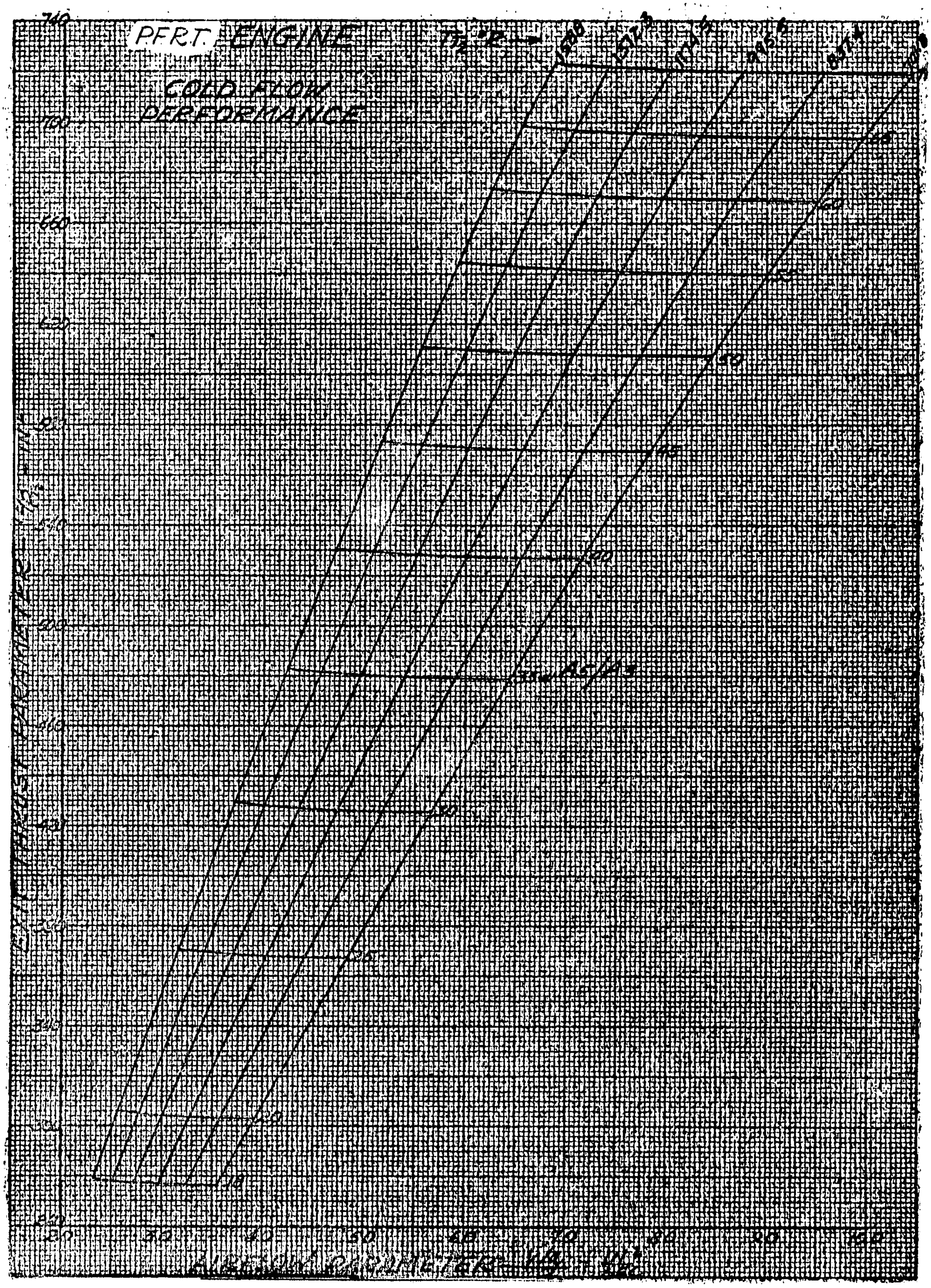

PERT ENGINE
CRUISE PERFORMANCE
T_{T_2} = 1696.1°R = 1236.1°F
MAXIMUM CONTINUOUS OPERATION AT T_{T_4} = 3375°R AND BELOW FOR $W_{a_{MAX}}$ = 51.8#/SEC AND AT T_{T_4} = 3650°R AND BELOW FOR $W_{a_{MAX}}$ = 44#/SEC
F/A
A5/A3 ~ .26
.24
.22
.28
WF/P_{T_2}
T_{T_4} = 2517°R (MIN POWER OPERATION)
REVISION - 2
EXIT THRUST PARAMETER - T_4/P_{T_2} - IN²
AIRFLOW PARAMETER - W_a/P_{T_2} - IN²/SEC

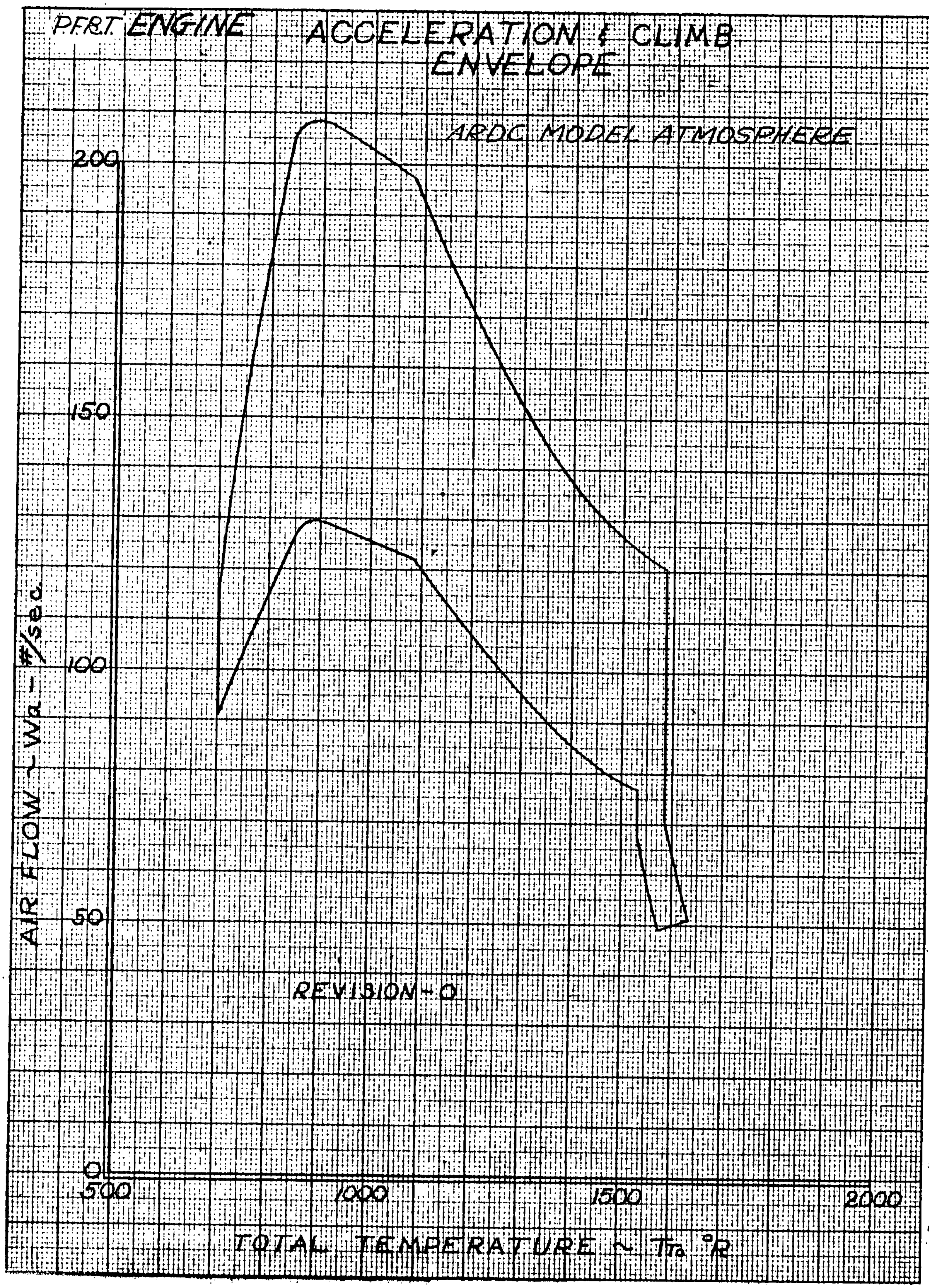

PFRT ENGINE
CRUISE PERFORMANCE
T_{T_2} = 1732.6°R = 1272.6°F
MAXIMUM CONTINUOUS
OPERATION AT T_{T_4} = 3375°R AND
BELOW FOR $W_{a_{MAX}}$ = 51.8 #/SEC
AND AT T_{T_4} = 3650°R AND
BELOW FOR $W_{a_{MAX}}$ = 44 #/SEC
F/A
A5/A3 → .22
W_f/P_{T_2}
REVISION - 2
(MIN POWER OPERATION)
EXIT THRUST PARAMETER - $\frac{T_e}{P_{T_2}}$ - IN^2
AIRFLOW PARAMETER - $\frac{W_a}{P_{T_2}}$ - $\frac{IN^2}{SEC}$


PFRT ENGINE
CRUISE PERFORMANCE
F/A
MAXIMUM CONTINUOUS
REVISION - 2
AIRFLOW PARAMETER
EXIT THRUST PARAMETER
18
19
20
21
22
23
24
25
330
340
350
360
370
380
390
400
410
420

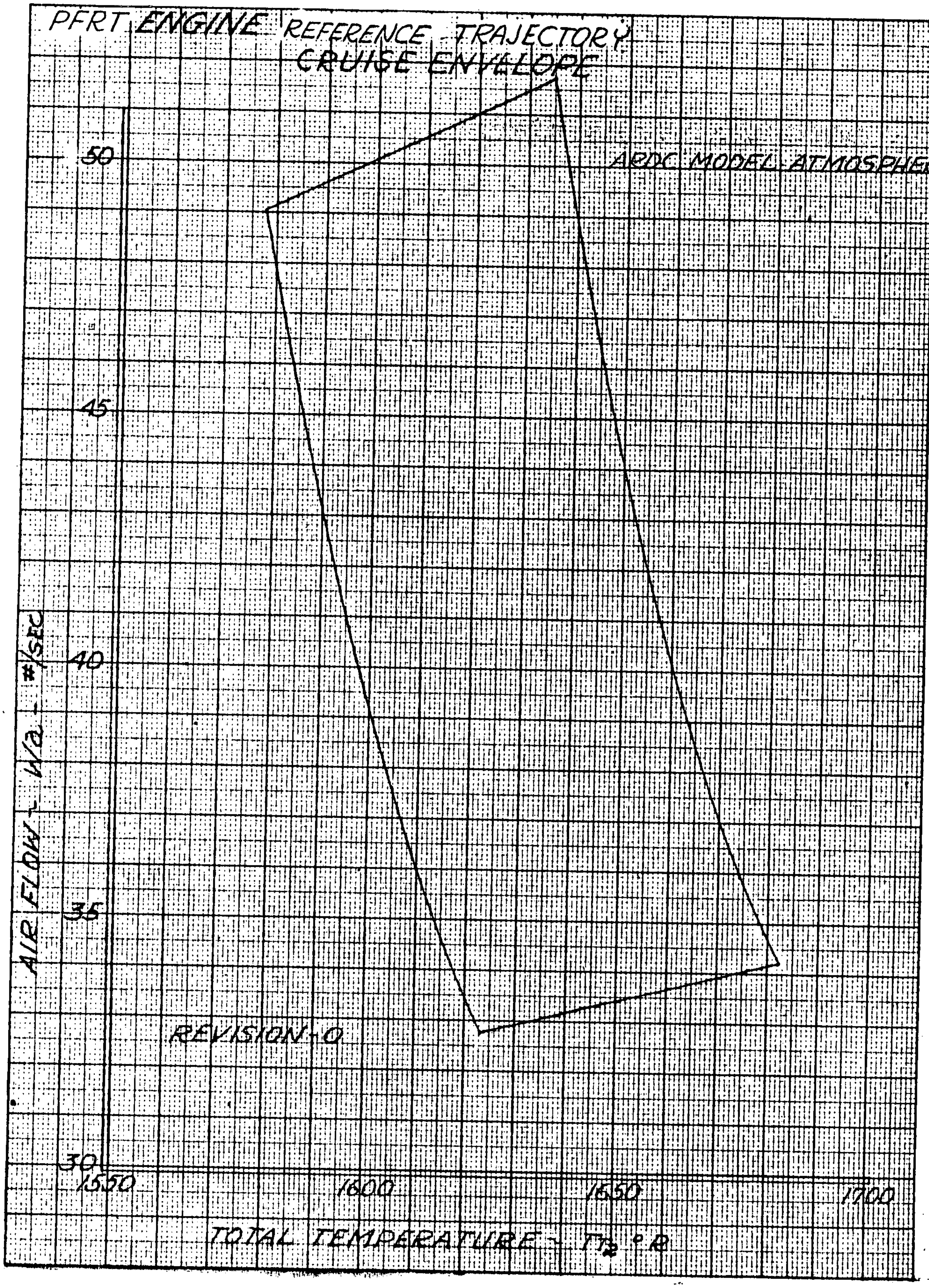

DHF
1/21/60
REFERENCE TRAJECTORY
PERT ENGINE
ARDC MODEL ATMOSPHERE
AIRFLOW ~ W2 ~ #/SEC
150
100
50
0
TOTAL TEMPERATURE ~ TT2 °R X 100
18
16
14
12
10
8
6
0
2
4
6
8
10
TIME ~ HOURS


DHF
1/21/60
IGNITION & REIGNITION
ENVELOPES
RERT ENGINE
ARDC MODEL ATMOSPHERE
220
200
180
160
140
120
100
80
60
40
20
4
6
8
10
12
14
16
18
AIRFLOW ~ Wa ~ #/SEC
TOTAL TEMPERATURE ~ T_{T0} °R × 100

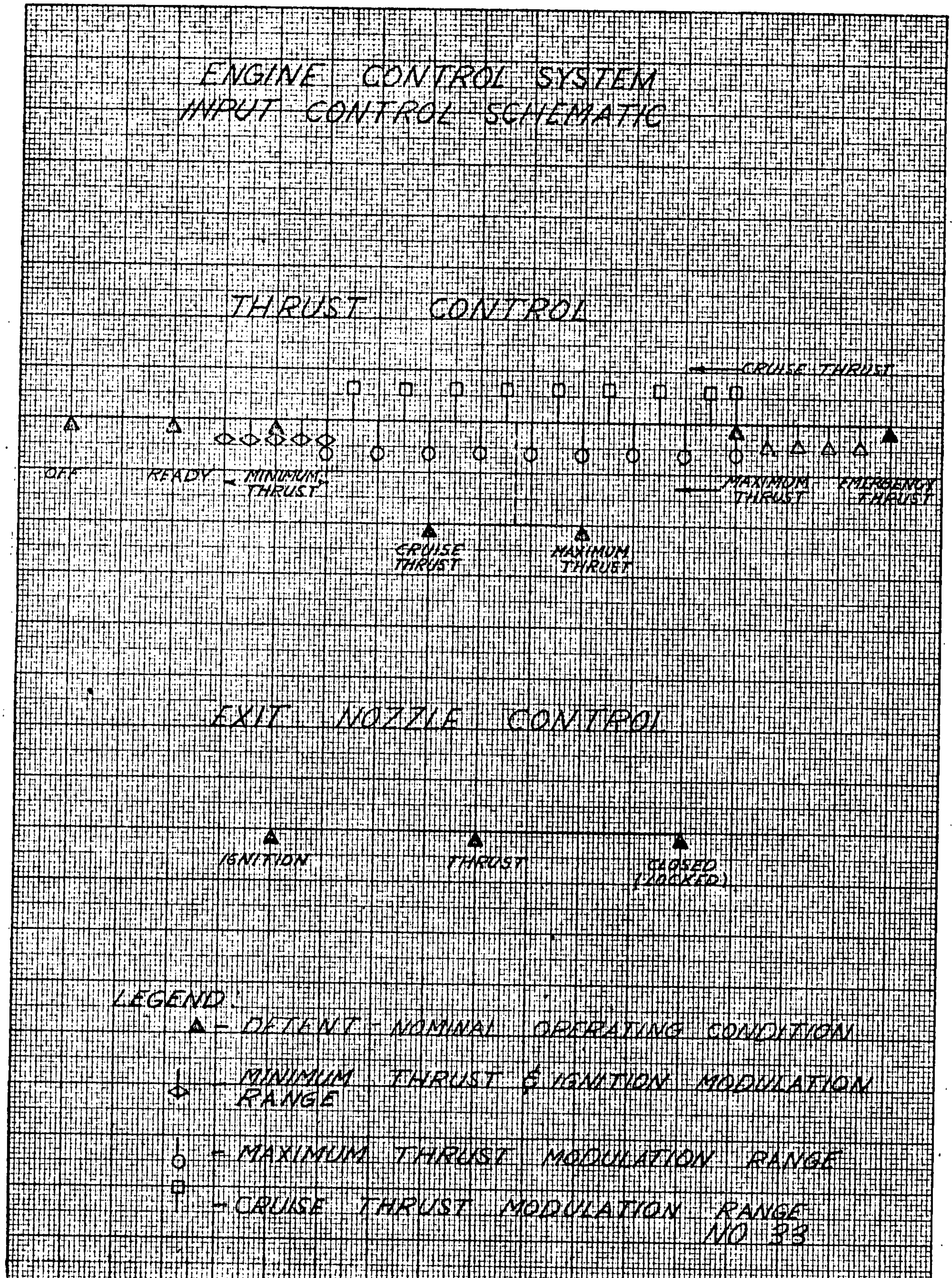

PFRT ENGINE
COLD FLOW
PERFORMANCE
740
700
660
620
20
30
40
50
60
70
80
90
100


PF&RT ENGINE ACCELERATION & CLIMB ENVELOPE
ARDC MODEL ATMOSPHERE
200
150
100
50
0
AIR FLOW ~ Wa - #/sec.
500
1000
1500
2000
TOTAL TEMPERATURE ~ Tto °R
REVISION - O

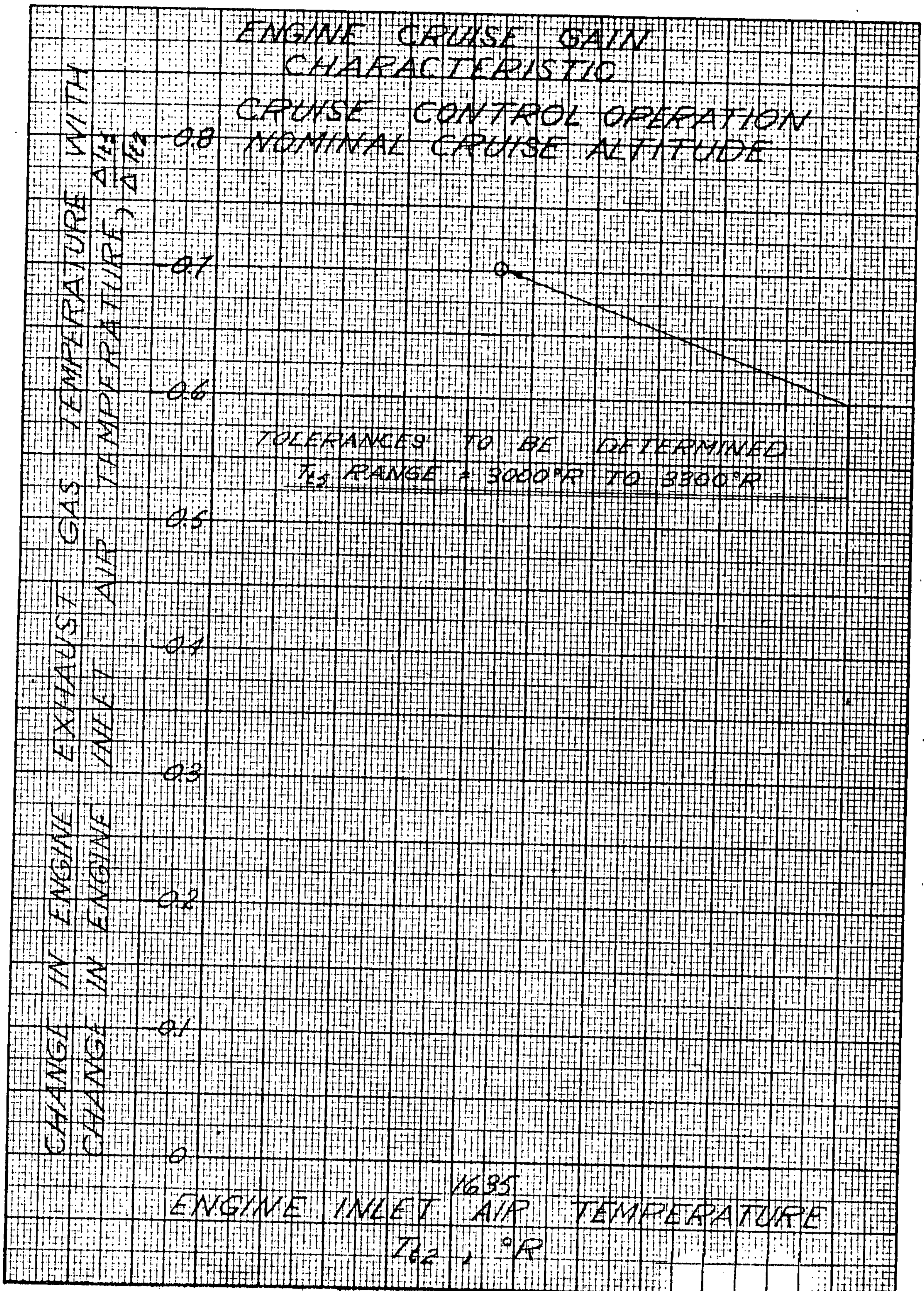
IAC A673

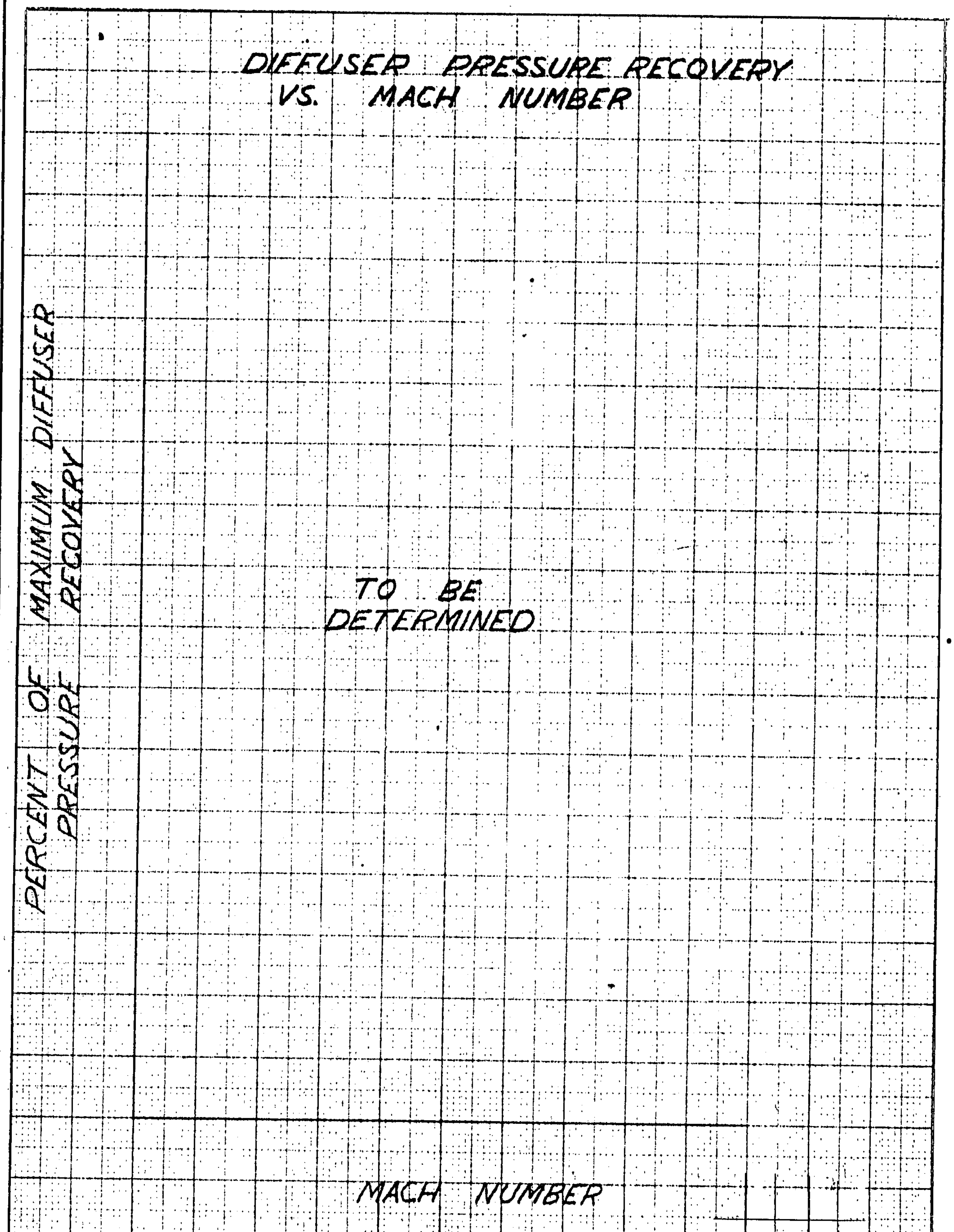

PFRT ENGINE REFERENCE TRAJECTORY
CRUISE ENVELOPE
ARDC MODEL ATMOSPHERE
REVISION O
AIR FLOW - Wa - #/SEC
50
45
40
35
30
1550
1600
1650
1700
TOTAL TEMPERATURE - T_{T2} °R

IAC A673

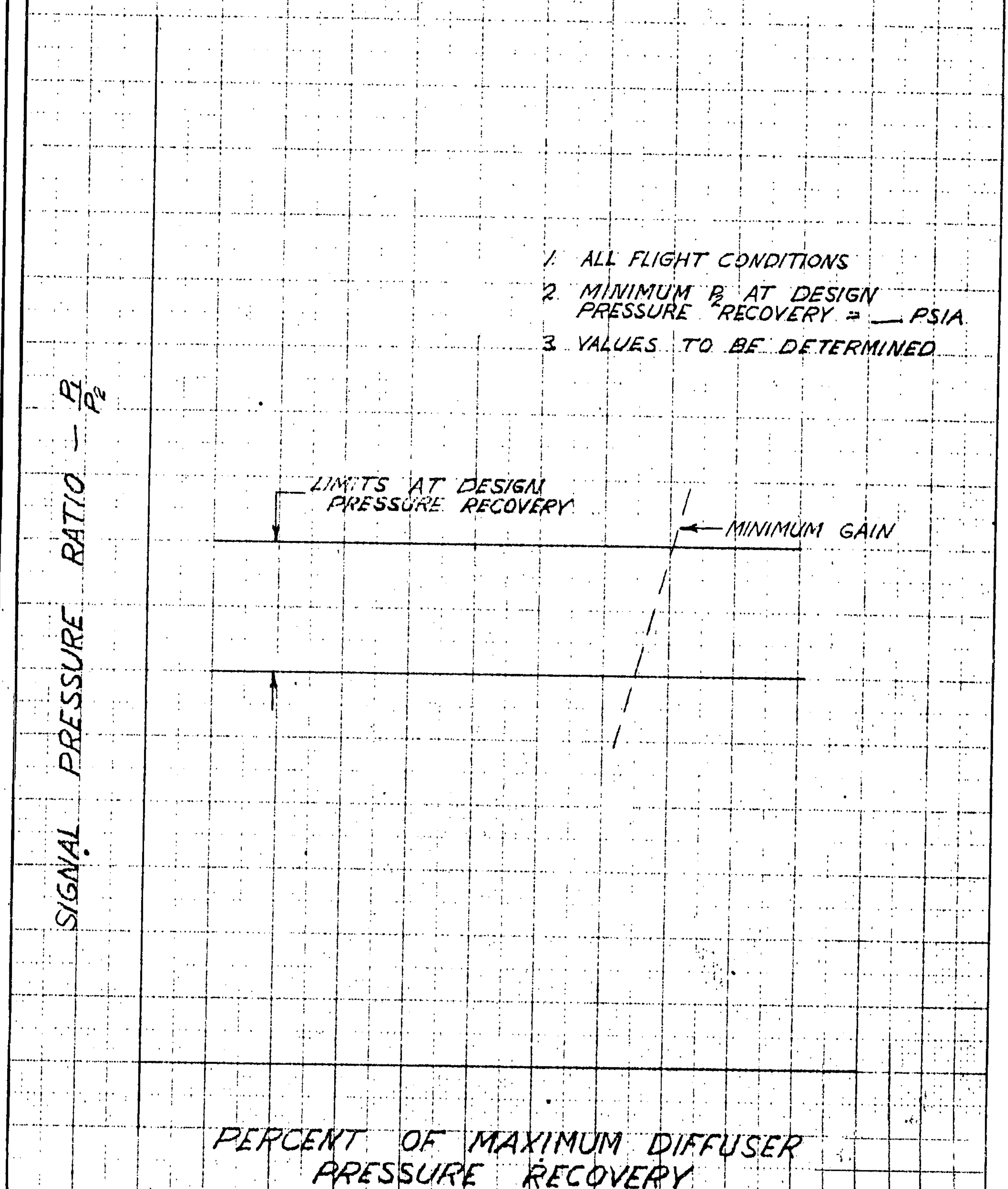

ENGINE CONTROL SYSTEM
INPUT CONTROL SCHEMATIC
THRUST CONTROL
CRUISE THRUST
OFF
READY
MINIMUM THRUST
MAXIMUM THRUST
EMERGENCY THRUST
CRUISE THRUST
MAXIMUM THRUST
EXIT NOZZLE CONTROL
IGNITION
THRUST
CLOSED (LOCKED)
LEGEND:
- DETENT - NOMINAL OPERATING CONDITION
- MINIMUM THRUST & IGNITION MODULATION RANGE
- MAXIMUM THRUST MODULATION RANGE
- CRUISE THRUST MODULATION RANGE

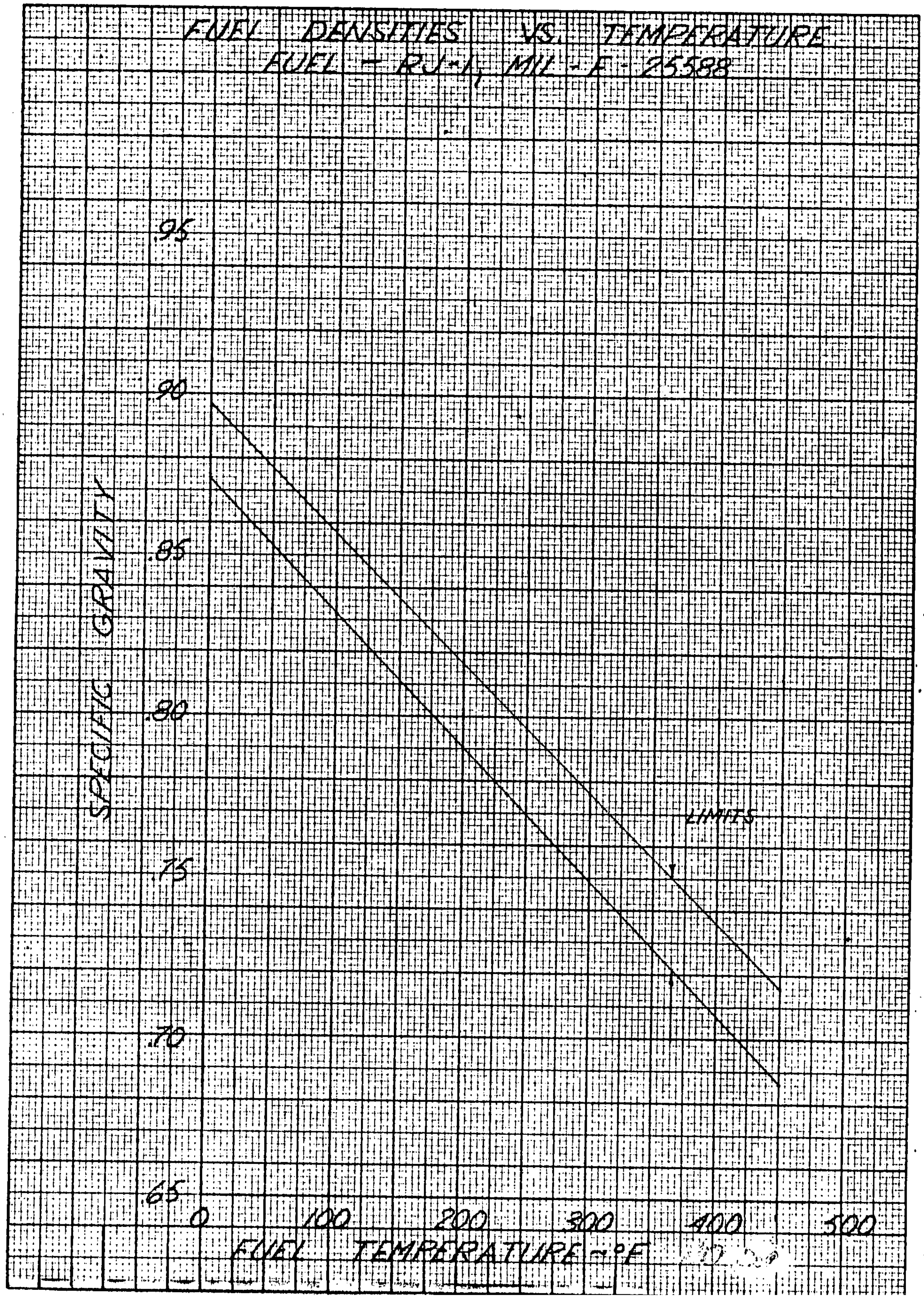
NO 33


ENGINE CRUISE GAIN CHARACTERISTIC
CRUISE CONTROL OPERATION
NOMINAL CRUISE ALTITUDE
TOLERANCES TO BE DETERMINED
T4 RANGE = 3000°R TO 3300°R
CHANGE IN ENGINE EXHAUST GAS TEMPERATURE WITH
CHANGE IN ENGINE INLET AIR TEMPERATURE, ΔT4/ΔT2
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1635
ENGINE INLET AIR TEMPERATURE
T2, °R

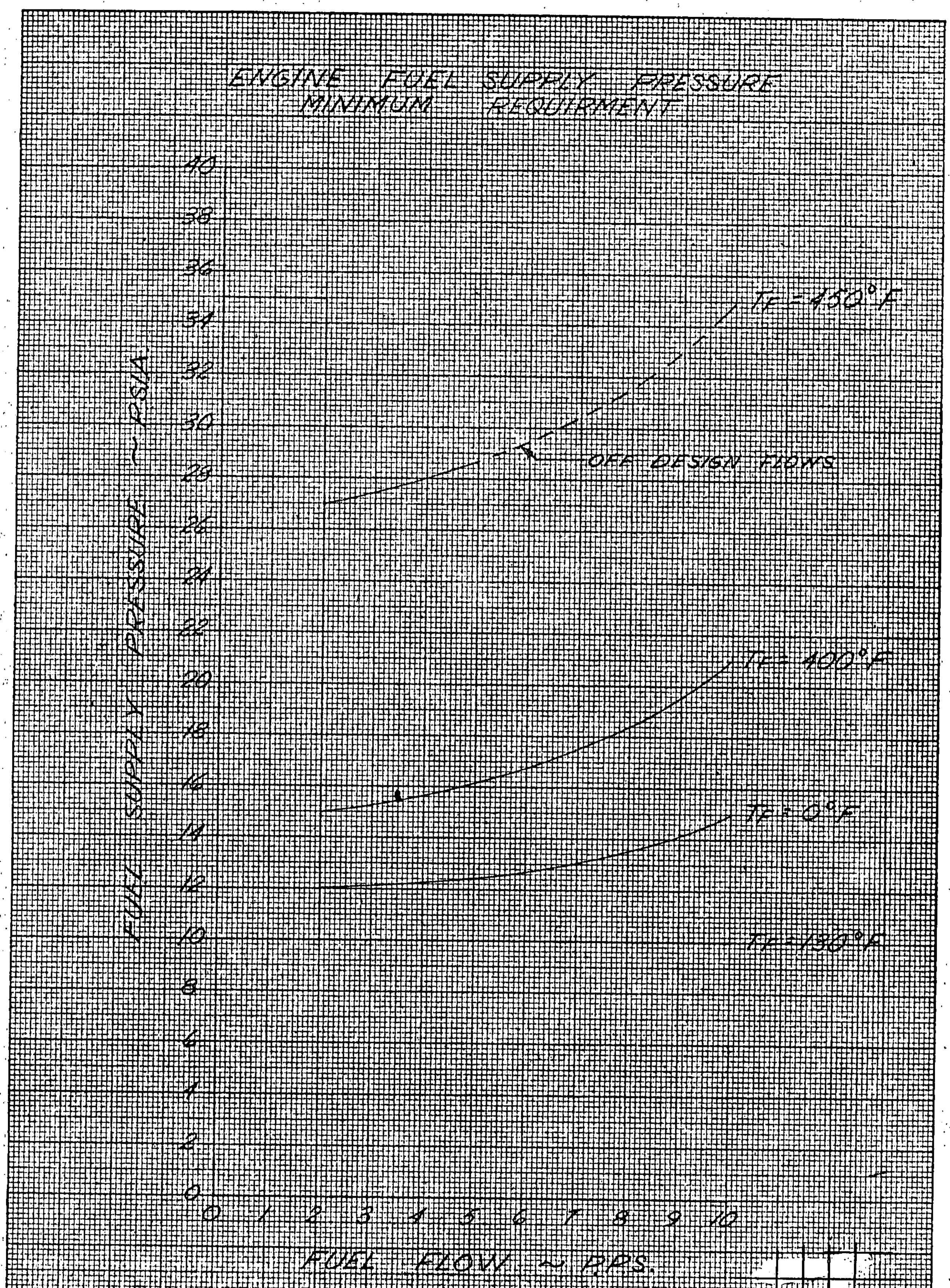

DIFFUSER PRESSURE RECOVERY
VS. MACH NUMBER
PERCENT OF MAXIMUM DIFFUSER
PRESSURE RECOVERY
TO BE
DETERMINED
MACH NUMBER

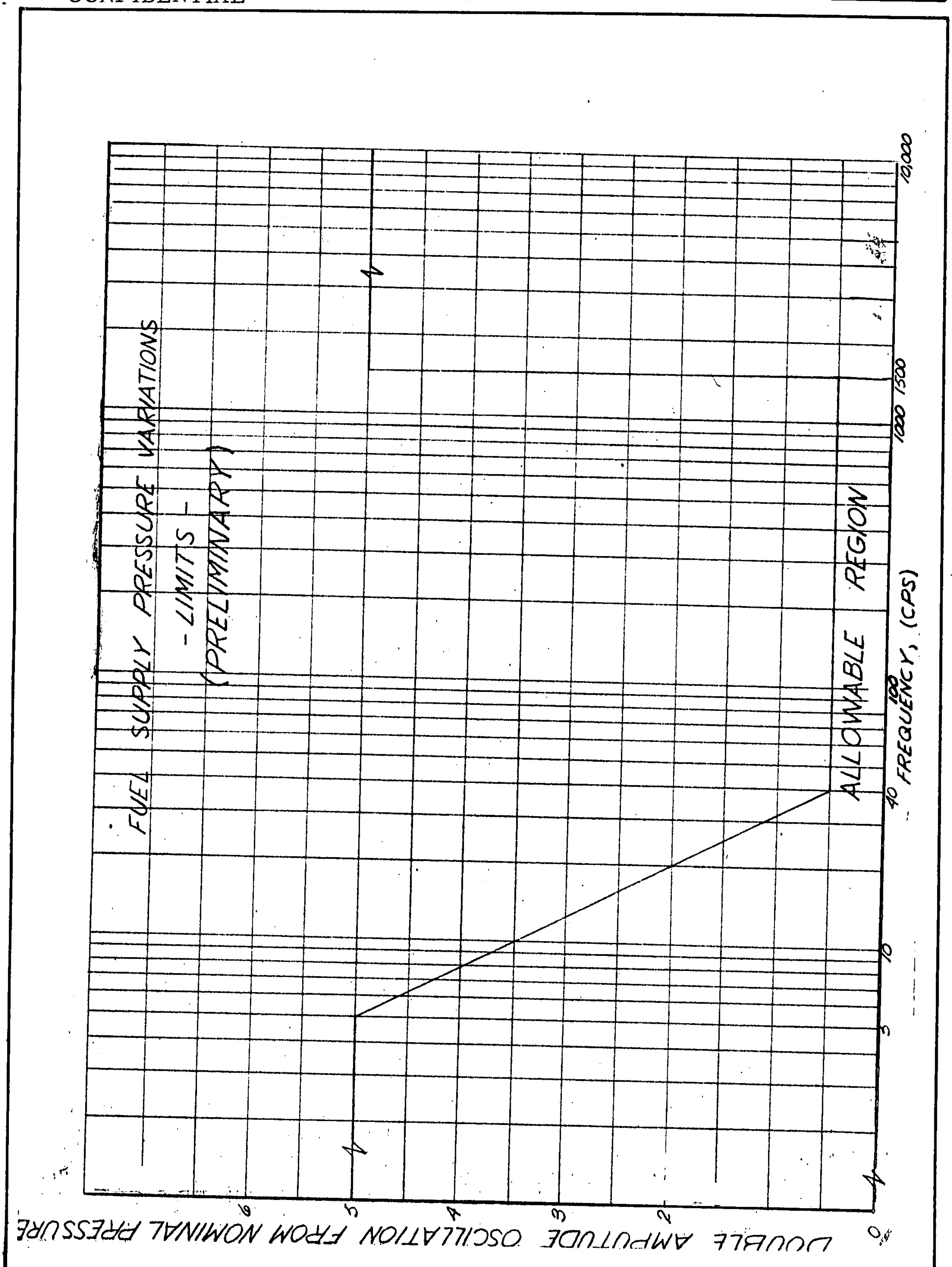
PNEUMATIC SIGNAL CHARACTERISTICS
DIFFUSER PRESSURE RECOVERY



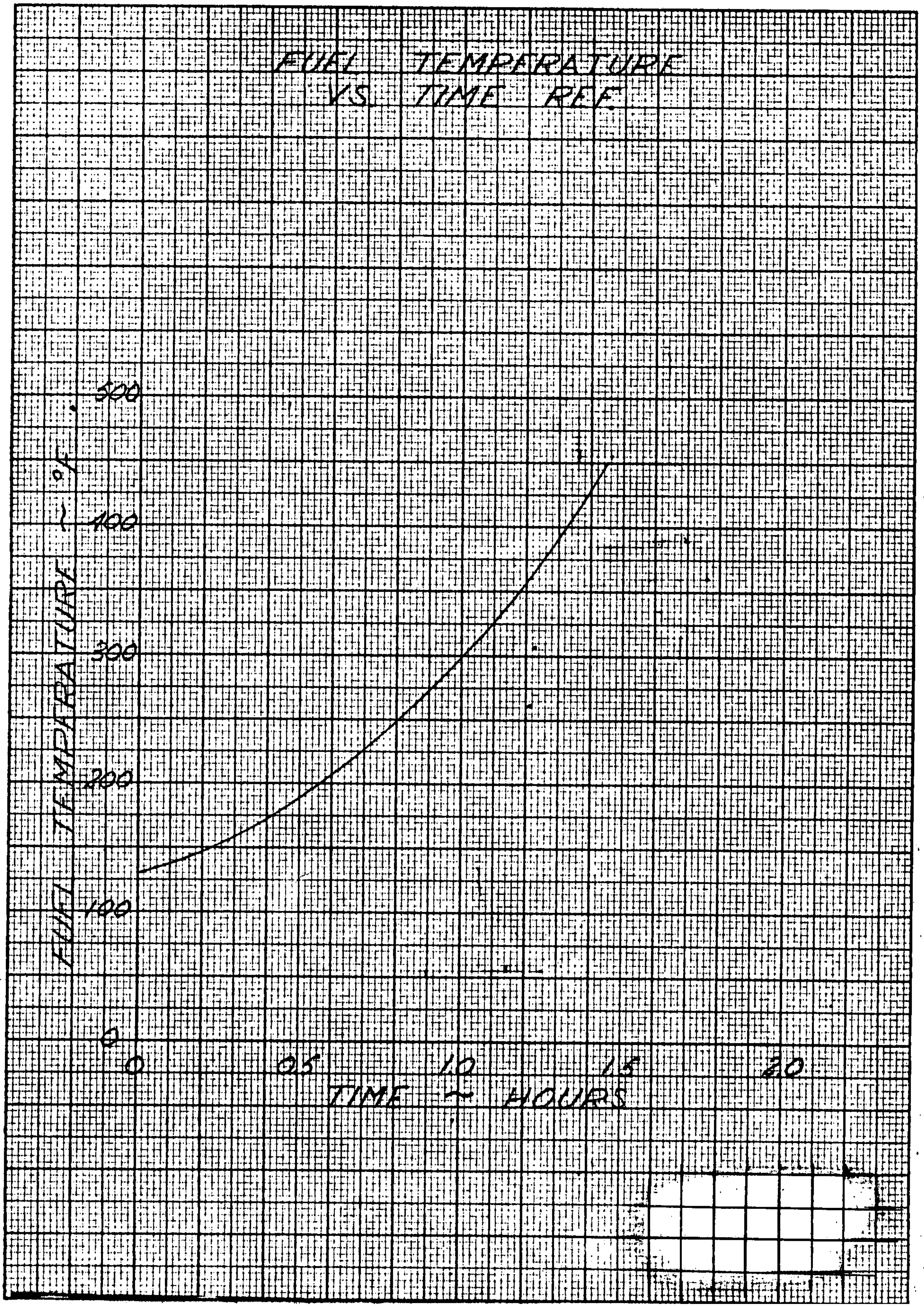

FUEL DENSITIES VS. TEMPERATURE
FUEL - RJ-1, MIL-F-25588
SPECIFIC GRAVITY
.95
.90
.85
.80
.75
.70
.65
LIMITS
0
100
200
300
400
500
FUEL TEMPERATURE - °F

AC A673


ENGINE FUEL SUPPLY PRESSURE
MINIMUM REQUIREMENT
FUEL SUPPLY PRESSURE ~ PSIA
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
TF = 450°F
OFF DESIGN FLOWS
TF = 400°F
TF = 0°F
TF = 130°F
0 1 2 3 4 5 6 7 8 9 10
FUEL FLOW ~ PPS.


FUEL SUPPLY PRESSURE VARIATIONS
- LIMITS -
(PRELIMINARY)
ALLOWABLE REGION
FREQUENCY, (CPS)
10,000
1000 1500
100
40
10
5
DOUBLE AMPLITUDE OSCILLATION FROM NOMINAL PRESSURE
0
2
3
4
5
6

AC A673


FUEL TEMPERATURE
VS. TIME REF.
FUEL TEMPERATURE ~ °F
500
400
300
200
100
0
0
0.5
1.0
1.5
2.0
TIME ~ HOURS

SECTION II

AIR INDUCTION CONTROL & ACTUATION SYSTEM

NOTE

* Deflection of items so marked pending receipt of suitable inlet data.

** Deflection of items so marked pending application.

MODEL SPECIFICATION
AIR INDUCTION CONTROL & ACTUATION SYSTEM

1. SCOPE

1.1. Scope.- This specification describes the design, performance, and test procedures for the variable geometry air induction control and actuation system of the ramjet powered aircraft, designated ______.

2. APPLICABLE DOCUMENTS

3. SYSTEM DESIGN

3.1. System Description.-

3.1.1. Functions.-

3.1.1.1. Primary Function.- The primary function of the air induction control and actuation system described herein shall be to position the variable geometry surfaces of the air induction system in such a manner as to provide the pressure recovery and air flow matching required for satisfactory operation of the propulsion system anywhere along the flight path defined in Figure A-37 of this specification. This function shall be accomplished as follows:

a. The ramp control system shall position the inlet ramps to hold throat parameter pressure ratio P_{th}/P_{t_1}'* constant (See Figure A-38). The control system shall be of the closed loop type with the loop closed aerodymanically through the inlet.

b. The bypass control system shall position the inlet by-pass doors in such a manner as to maintain the normal shock parameter pressure ratio P_{t_3}/P_{t_2}'* (Reference Figure A-38) constant. The system shall be of the closed loop type with the loop closed through the engine.

3.1.1.2. Restarting.- The air induction control system shall provide for automatic restarting of the inlet in case of normal shock expulsion anywhere along the flight path specified in Figure A-37 of this specification.

3.1.1.3. Manual Options.- Solenoid operated switches in the pilot compartment shall provide the following modes of operation:

a. Ramp System.-

"Extend".- The controller is overridden to hold the ramps in the fully extended position.

"Retract".- The controller is overridden to hold the ramps in the fully retracted position.

"Auto".- This setting releases the controller for normal, automatic operation in accordance with the requirements set forth in this specification.

b. Bypass System.-

"Open".- The controller is overridden to hold the bypass doors in the fully open position.

"Closed".- The controller is overridden to hold the bypass doors in the fully closed position.

"Auto".- This setting releases the controlled for normal, automatic operation in accordance with the requirements of this specification.

3.1.1.4. Dual Systems.- The actuation portion of the air induction control and actuation system shall be duplicated to provide for operation of two completely independent hydraulic supply systems. The actuators of each of the two independent systems shall be capable of operating the variable geometry surfaces with the other system failed at all conditions in the flight envelope at and above 80,000 feet altitude.

Two ramp controllers and associated probes shall be provided with one of the two serving normally as a standby unit. Switching from one controller to the other shall be accomplished manually from the pilot compartment.

3.1.2. Block Diagrams.- Block diagrams for the ramp and the bypass control systems are shown in Figure A-39 and Figure A-40, respectively.

3.1.3. Components.- The complete air induction control and actuation system shall consist of one ramp positioning system and two independent bypass door positioning systems. The ramp positioning system shall serve both engine inlets. Each of the bypass door systems shall serve one of the inlet ducts.

3.1.3.1. Ramp Positioning System.- The system comprises the following components:

2 Ramp controllers

1 Servo unit

2 Ramp actuators

4 Probes

3.1.3.1.1. Ramp Controller.- The ramp controller shall be a pneumatic sensing and computing device with electro-pneumatic valves added for manual commands. The electro-pneumatic valves shall be actuated by a three-position mode and a two-position selector switch in the pilot compartment.

With the mode switch in the "Auto" position the controller senses the actual value of the throat parameter pressure ratio, P_{th}/P_{t_1}', compares it to the desired fixed value and regulates a pneumatic output to the servo unit such as to move the ramps in the direction to correct the error. With the mode switch in the "extend" or "retract" position the pneumatic output signal is biased such as to cause the servo unit to port hydraulic pressure to either side of the actuators to hydraulically lock the ramps in the extended or retracted position respectively.

The controller shall be designed in accordance with the requirements specified in paragraph 4.2. of this specification.

3.1.3.1.2. Ramp Servo Unit.- The ramp servo unit shall be a pneumatic-hydraulic device which converts the pneumatic signal generated by the ramp controller into a hydraulic output to the ramp actuators. The unit contains two hydraulic servo valves, one for each actuator and the corresponding supply system. These servos are operated by a common pneumatic piston. Two unloading valves are incorporated, one for each actuator, which connect both ports of an actuator to system return in case of a supply system failure. These valves are held in the nominal position by the system supply pressure.

The servo unit shall be cooled by separate flow of hydraulic fluid from both supply systems. The hydraulic flows from the two independent supply systems are completely separated to prevent any possibility of cross flow in case of failure of one of the supply systems (See flow schematics in Figure A-41 of this specification).

Design of the ramp servo unit will be in accordance with the requirements of paragraph 4.4 of this specification.

3.1.3.1.3. Ramp Actuators.- The actuators will be of the linear piston hydraulic type. Synchronization of the two actuators in the system will be achieved mechanically in the airframe portion of the ramp actuation system. The actuators will be cooled by a separate cooling flow circuit off the hydraulic supply going to the particular actuator as shown in Figure A-41 of this specification. The actuators will be designed in accordance with the requirements of paragraph 4.6 of this specification.

3.1.3.2. Bypass Positioning System.- Each of the two bypass positioning systems shall consist of the following components:

1 Bypass controller

1 Servo unit

2 Bypass actuators

2 Probes

3.1.3.2.1. Bypass Controller.- The bypass controller shall be a pneumatic sensing and computing device which generates a pneumatic output to the servo unit. An electro-pneumatic valve provides for manual inputs from a three-position mode switch in the pilot's compartment.

With the mode switch in the "Auto" position, the controller senses the actual value of the shock position parameter ratio P_{t_3}/P_{t_2}', compares it to the desired fixed value, and regulates a pneumatic output to the servo unit in such a manner as to move the bypass doors in the direction of removing any existing error. With the mode switch in the "open" or "close" position, the pneumatic output signal is biased in such a manner that the servo unit ports hydraulic fluid to one side or the other of the actuators. This will hold the bypass door in the fully open or closed position, respectively.

The controller shall be designed in accordance with the requirements of paragraph 4.3 of this specification.

3.1.3.2.2. Bypass Servo Unit.- The bypass servo unit is a pneumatic-hydraulic device which converts the pneumatic signal generated by the bypass controller into a hydraulic output to the bypass actuators. The unit contains two hydraulic servo valves, one for each actuator and the corresponding supply system. These servos are operated by a common pneumatic piston. Two unloading valves are incorporated, one for each actuator, which connect both ports of an actuator to system return in case of a supply system failure. These valves are held in the normal position by the system supply pressure.

The servo unit is cooled by separate flow of hydraulic fluid from both supply systems. The hydraulic flows from the two independent supply systems are completely separated to prevent any possibility of cross flow in case of failure of one of the supply systems (See flow schematics in Figure A-42 of this specification).

Design of the bypass servo unit shall be in accordance with the requirements of paragraph 4.5 of this specification.

3.1.3.2.3. Bypass Actuators.- The bypass actuators shall be of the linear piston hydraulic type. Synchronization of the two actuators in the system will be achieved mechanically in the airframe portion of the ramp actuation system. The actuators will be cooled by a separate cooling flow circuit off the hydraulic supply going to the particular actuator as shown in Figure A-42 of this specification. The actuators shall be designed in accordance with the requirements of paragraph 4.7 of this specification.

3.1.3.3. Probes.- Suitable probes will be installed on the inlet and in the inlet duct to provide the controllers with the necessary pneumatic signals and the servo units with pneumatic power. These probes will be located as shown in Figure A-43 of this specification*. Location, type, and characteristics of these probes will be determined on the basis of inlet test data to be supplied by the air frame contractor. The probes shall be designed in accordance with the requirements specified in paragraph 4.8 of this specification.

3.1.3.4. Heat Exchanger.- An air-to-oil heat exchanger shall be incorporated in the main pneumatic supply, P_{t4}, to the controllers and the servo units. This heat exchanger cools the air which flows through the ramp and bypass controllers to a level commensurate with the operating temperature of these units. The purpose of cooling the air to the servo boosters is to prevent local overheating of the working fluid in these units. Cooling will be accomplished by completely independent hydraulic flows from the two supply systems as shown in Figure A-41 of this specification. The heat exchanger shall be designed in accordance with paragraph 4.9 of this specification.

3.1.4. Operation.- Operation of the air induction control and actuation system is described in the following paragraphs and summarized in Table A-III for a typical mission and significant special conditions. Manual switches and instrumentation are shown in Figure A-44.

3.1.4.1. Take-off and Carry.- The air inlets are covered, the hydraulic systems de-energized. Position of the mode switches is immaterial in the absence of hydraulic and pneumatic power.

3.1.4.2. Prelaunch.- The pilot switches the ramp and the bypass systems on "auto". The inlet covers are removed and the hydraulic systems are energized. The ramps cycle to start the inlet, the bypass modulates as required to permit the normal shock to be swallowed. After the starting transient and prior to ignition, the bypass doors close. The inlet operates supercritically with the engine exit nozzle in ignition position. During ignition of the engine and the engine check-out precedure, the bypass doors modulate the bypass flow as required to maintain specified critical operation. The inlet instrumentation shown in Figure A-44 allows the pilot to monitor all inlet operations by observing the position indicators and the mode indicator lights.

3.1.4.3. Launch, Acceleration, Climb, and Cruise.- The ramps extend and retract automatically as required to maintain the correct throat parameter value. The bypass doors modulate as required to maintain specified critical (inlet operation), closing gradually as flight Mach number increases. The bypass doors reach the fully closed position at the Mach number where inlet and engine air flow match with the engine exit nozzle wide open. From this point on, the bypass doors remain normally closed and the exit nozzle takes over on the critical control. During fast transients, which the exit nozzle cannot follow, the bypass doors will open temporarily to prevent expulsion of the normal shock.

3.1.4.4. Descent.- During the first portion of the descent to condition (defined in Figure A-37), both systems continue to operate as before. Below this condition, the pilot switches the ramps to "retract", locking them hydraulically in the retracted position. Similarly, the bypass doors are hydraulically locked in the closed position by placing the bypass switch in the "close" position.

3.1.4.5. Inlet Restart.- In the case of shock expulsion (angle of attack transients beyond the specified capability of the system, etc.) the ramps cycle and the bypass doors open until the inlet is restarted. This occurs automatically. The pilot monitors the inlet restart by observing the motion of the ramp and bypass position indicators.

3.1.4.6. Hydraulic Systems Failure.- In case of a failure of one of the two independent hydraulic supplies, the unloading valves in the failed system automatically connect both sides of the actuators in this system to return to reduce the "drag" of these actuators to a minimum. The remaining actuators connected to the operative supply system will continue to operate as before, except for a reduction in performance commensurate with the actuator requirements of paragraphs 4.6 and 4.7.

3.1.4.7. Controller Failures.- If the operative ramp controller suffers a failure, which the pilot can detect by way of the inlet instrumentation (e.g. continuous cycling, drift to wrong position, etc.), the switches manually to the other controller. This isolates the failed controller from the system and permits normal operation of the ramp system.

In the case of a bypass controller failure, the pilot selects one of the two override positions, "close" or "open" depending on the type of failure and the point along the mission.

3.2. Performance.-

3.2.1. General.- The system performance specified in the following paragraphs is based on

a. The nominal hydraulic supply system requirements specified in paragraph 3.4.1 in this specification.

b. The actuator load and stroke requirements defined in paragraphs 4.6 and 4.7.

c. The structural requirements defined in paragraph 4.1.

3.2.2. Ramp Positioning System.-

3.2.2.1. Accuracy.- During steady state operating conditions, the ramp positioning system will maintain the throat parameter pressure ratio constant within ±_____%*.

When subjected to the maximum short duration acceleration loads defined in paragraph 4.1, the accuracy tolerance band will temporarily widen to ±_____%*.

3.2.2.2. Transients.- The ramp positioning system will be capable of positioning the ramps at a rate sufficient to prevent shock expulsion during aircraft angle of attack transients of 5°/second, provided that this transient condition does not result in other disturbances beyond the control of the ramp system which cause expulsion of the normal shock.

3.2.2.3. Ground Calibration.- Manual adjustments on the control will permit variation of the throat parameter pressure ratio P_{th}/P_{ti}' from ____ to ____.* Following calibration of the controller on the ground, these adjustments will be positively locked and will remain unchanged during the flight.

3.2.3. Bypass Positioning System.-

3.2.3.1. Accuracy.- During steady state operating conditions, the control system will control the normal shock (or shock train) such as to maintain ____% of critical pressure recovery within ± 0%*. The critical recovery referred to here is the maximum stable recovery attainable by the inlet at the specified condition.

When subjected to the maximum short duration acceleration loads defined in paragraph 4.1, the accuracy tolerance band will temporarily widen to ±____%*.

3.2.3.2. Transients.- The bypass positioning system will be capable of maintaining the specified percentage of critical operation during transients requiring a rate of change of the bypass area of ____sq ft/sec.*

3.2.3.3. Ground Adjustments.- The control will provide for ground adjustment of the shock position computer corresponding to ____ to ____* of critical recovery. After calibration on the ground to the desired value, the adjustment will be positively locked and remain unchanged during the flight.

3.3. Weight.- The weight of the complete air induction control and activation system as defined in paragraph 3.1.3. of this specification will be ____pounds. This is composed of the following individual weights:

2 Ramp controllers____pounds each**

1 Ramp servo unit____pounds

2 Bypass controllers____pounds each

2 Bypass servo units____pounds each

2 Ramp actuators____pounds each

4 Bypass actuators____pounds each

1 Heat exchanger____pounds

Probes, lines, and fitting, filters, etc.____pounds

3.4. Power Requirements.-

3.4.1. Hydraulic.- The air induction control and actuation system will meet the performance requirements specified herein when supplied with hydraulic fluid, Oronite 8515, Specification MIL-H-8556A, at the following conditions:

Pressure:	Supply	3000 nominal
		3050 psi maximum
		2250 psi minimum
	Return	60 to 80 psi nominal
		600 psi maximum
Temperature:	Inlet	-20 to 300°F
	Outlet	-20 to 350°F
Flow:		
Internal Leakage:	0.15 GMP per system for ramp actuation	
	0.15 GMP per system for bypass actuation	

3.4.1.1. Reduced performance of the system will be acceptable at fluid inlet temperatures between -65 and -20°F.

3.4.1.2. In addition to the actuation flow requirements, each of the supply systems must provide for continuous branch flows to the various system components requiring cooling as shown in Figures A-41 and A-42. Metering and throttling of these cooling flows will be achieved by fixed orifices at the inlet to each component. The cooling flows required by each component are shown in Figures A-41 and A-42. The total cooling flow required per supply system will not exceed ___ GMP.**

3.4.2. Electrical.- Operation of the manual inputs to the system requires an electrical power supply of 28 volts d-c. Power ratings will be as specified in the applicable component sections under paragraph 4.0 of this specification.

3.4.3. Pneumatic.- The pneumatic power supply will be obtained from the air induction system by means of the probes furnished as part of the equipment covered by this specification and defined in paragraphs 4.8. Airframe furnished transmission lines shall be in accordance with the requirements shown in Figure A-45 of this specification.

4. COMPONENT DESIGN

4.1. General Structural Requirements.- All components covered by this specification will meet the general design requirements listed in the following paragraphs.

4.1.1. Life.- The components will be designed for a minimum operational life of 50 hours, except where otherwise specified in the detailed component specifications herein. Demonstration of this life by test will not be required except where noted specifically in the detailed requirements.

4.1.2. Flight Maneuver Loads.- All components covered by this specification will be capable of withstanding the flight maneuver loads specified in the following paragraphs without suffering damage or deterioration of performance. All attachments and connections will be designed to withstand these loads without breaking or permanent deformation.

4.1.2.1. Vibration.- The components will operate satisfactorily when subjected to vibrations within the operating vibration spectrum shown in Figure A-46. Mean values of performance (RMS) will be within the tolerances defined in the individual component performance specifications below, unless otherwise noted therein. Nonoperating vibrations shall not exceed those shown in Figure A-46.

4.1.2.2. Acceleration.- All components covered by this specification will operate satisfactorily when subjected to the acceleration conditions specified below. Performance deviations will not exceed those specified in the individual component performance requirements. Nonoperating acceleration limits shall not exceed the values specified below.

4.1.2.3. Shock.- The equipment covered by this specification will perform in accordance with the performance specified herein after having been subjected to the shock conditions specified below.

4.2. Ramp Controller.-

4.2.1. Performance.-*

4.2.2. Weight.- The weight of the ramp controller, including all fittings, solenoid valves and electrical connectors will be ___lbs.**

4.2.3. Space.- The controller will fit within the space envelope shown in Figure A-47 of this specification. Attachments, pneumatic connections, and electrical connections will be as shown in Specification Drawing ___. Orientation of the controller in the vehicle shall be as shown on this drawing.

4.2.4. Environment.- The controller will operate under the following environmental conditions:

Ambient pressure: 0.1 to 15 psia

Ambient temperature: -65 to 300°F

4.2.5. Endurance.- Endurance of the controller will be demonstrated during the evaluation test (FRT) defined in paragraph 5.0 of this specification.

4.2.6. Electrical Power.- The power ratings of the Mach number switch and selector switch solenoids will be as shown in Figure A-48.

4.3. Bypass Controller.-

4.3.1. Performance.-*

4.3.2. Weight.- The weight of the bypass controller, including all fittings, solenoid valves and electrical connectors, will be ___lbs.**

4.3.3. Space.- The controller will fit within the space envelope shown in Figure A-49 of this specification. Attachments, pneumatic connections, and electrical connections will be as shown in specification drawing ___. Orientation of the controller in the vehicle shall be as shown on this drawing.

4.2.4. Environment.- The controller will operate under the following environmental conditions:

Ambient pressure: 0.1 to 15 psia

Ambient temperature: -65 to 300°F

4.3.5. Endurance.- Endurance of the controller will be demonstrated during the evaluation test (FRT) defined in paragraph 5.0 of this specification.

4.3.6. Electrical Power.- The power rating of the mode switch solenoid will be as specified in Figure A-48 of this specification.

4.4. Ramp Servo Unit.-

4.4.1. Performance.-*

4.4.2. Weight.- The dry weight of the ramp servo unit, including all pneumatic and hydraulic fittings, insulation, will not exceed ___lbs.**

4.4.3. Space.- The space envelope of the ramp servo unit including insulation will not exceed that shown in Figure A-50 of this specification. Mounting provisions, pneumatic connections, and hydraulic connections will be as shown in Specification Drawing ___. Orientation of the unit in the vehicle shall be as indicated on this drawing.

4.4.4. Environment.- The servo unit will operate under the environment specified in the following provided that the hydraulic cooling flow requirements shown in Figure A-41 are met:

Ambient pressure: 0.1 to 90 psia

Ambient temperature: -65 to 1175°F

4.4.5. Endurance.- Endurance of the servo unit will be demonstrated during the evaluation tests (FRT) defined in paragraph 5.0 of this specification.

4.5. Bypass Servo Unit.-

4.5.1. Performance.-*

4.5.2. Weight.- The dry weight of the bypass servo unit, including all pneumatic and hydraulic fittings and insulation, will not exceed ____lbs.**

4.5.3. Space.- The space envelope of the bypass servo unit, including insulation, will not exceed that shown in Figure A-50 of this specification. Mounting provisions, pneumatic connections, and hydraulic connections will be as shown in Specification Drawing ____. Orientation of the unit in the vehicle shall be as indicated on this drawing.

4.5.4. Environment.- The servo unit will operate under the environment specified in the following provided that the hydraulic cooling flow requirements shown in Figure A-41 are met:

Ambient pressure: 0.1 to 90 psia

Ambient temperature: -65 to 1175°F

4.5.5. Endurance.- Endurance of the servo unit will be demonstrated during the evaluation tests (FRT) defined in paragraph 5.0 of this specification.

4.6. Ramp Actuators.-

4.6.1. Performance.-**

Load

Stroke

Rate

Internal leakage

4.6.2. Weight.- The dry weight of the ramp actuator including fittings and insulation will be ___lbs.**

4.6.3. Space.- The actuator space requirements, including insulation, will be as shown in Figure A-50 of this specification. Mounting provisions and orientation in the vehicle will be as shown in Specification Drawing ____.

4.6.4. Environment.- The actuator will operate in the environment specified below provided that the hydraulic cooling flow shown in Figure A-41 are provided:

Ambient pressure: 0.1 to 90 psia

Ambient temperature: -65 to 1175°F

4.6.5. Endurance.- The actuator will be designed to pass the endurance test specified in the applicable test requirements under paragraph 5.0 of this specification.

4.7. Bypass Actuator.-

4.7.1. Performance.-** (Figure A-51)

Load

Stroke

Rate

Internal leakage

4.7.2. Weight.- The dry weight of the bypass actuator including fittings and insulation will be ___lbs.**

4.7.3. Space.- The actuator space requirements, including insulation, will be as shown in Figure A-50 of this specification. Mounting provisions and orientation in the vehicle will be as shown in Specification Drawing ____.

4.7.4. Environment.- The actuator will operate in the environment specified below provided that the hydraulic cooling flow shown in Figure A-41 are provided:

Ambient pressure: 0.1 to 90 psia

Ambient temperature: -65 to 1175°F

4.7.5. Endurance.- The actuator will be designed to pass the endurance tests specified in the applicable test requirements under paragraph 5.0 of this specification.

4.8. Probes.-

4.9. Heat Exchanger.-**

5. PRELIMINARY FLIGHT RATING TESTS (PFRT)

5.1. Selection.- One complete system each of the ramp positioning system and the bypass positioning system, consisting of controller, servo unit and actuators, will be subjected to the tests described in the following paragraphs. Systems used in these tests shall have passed the acceptance test outlined in paragraph 6 of this specification.

5.2. Test Setup.- The tests will be performed at the contractors facility on suitable pneumatic-hydraulic benches. Input signals, actuator loads, and environment will be provided to simulate actual flight conditions as closely as possible. Instrumentation will be provided to measure all quantities necessary to establish that the equipment meets the performance described in the specification.

5.3. Test Procedure.-

5.3.1. Calibration.- Prior to the PFRT tests, the system will be calibrated on the bench to assure conformance with the design tolerance requirements of this specification.

5.3.2. Procedure.- Each system will be subjected to six simulated missions. Inputs, actuator loads, and environment will be varied to duplicate the progress of the flight as nearly as possible within the capability of the facility. (The exact extent of simulation shall be defined later.)

5.3.3. Test Data.- During the tests outlined in paragraph 5.3.2, sufficient data will be recorded to document the simulation of the flight mission as well as the performance of the control systems.

5.3.4. Recalibration.- Following completion of the tests specified in paragraph 5.3.2, the systems tested will be recalibrated to document conformance with the specification requirements.

5.4. Inspection.- After completion of the tests defined in paragraph 5.3, a teardown inspection of all the components will be performed to determine conformance of the equipment with specific design critieria (to be specified in the detailed test specifications).

5.5. Additional Component Tests.- The following component tests will be performed as part of the PFRT test.

5.5.1. Selection.- Components used for the tests described below shall have passed the acceptance tests outlined in paragraph 6 of this specification.

5.5.2. Description of Tests.-

5.5.2.1. Cold Soak Tests.- One specimen each of the following components will be subjected to this test:

Servo unit

Ramp actuator

Bypass actuator

Ramp controller

(Detailed test requirements to be specified by mutual agreement between contractor and customer.)

5.5.2.2. Contamination.- One servo unit will be subjected to tests with comtaminated hydraulic fluid. (Test procedure to be established.)

5.5.2.3. Probes.- (Test requirements for all probes to be established by mutual agreement when inlet data are available.)

5.5.2.4. Heat Exchanger.- (Test requirement to be established by mutual agreement at later date.)

6. ACCEPTANCE TESTS

6.1. Selection.- Acceptance tests will be performed on complete ramp and bypass positioning systems consisting of controller, servo unit, and actuators. All components of the systems submitted for acceptance testing must have passed the component tests specified below.

6.2. Test Setup.- Acceptance tests will be performed on suitable pneumatic-hydraulic benches at the contractors facility. Tests will be performed under the existing ambient environment.

6.3. Procedure.- (Test procedures are aimed at demonstrating specified performance. Detailed procedures to be as mutually agreed.)

6.4. Component Tests.- (Proof pressures, leakage, etc., to be as mutually agreed at a later date.)

6.5. Reports.- Acceptance tests will be recorded in a log book for each system, copies of which will be supplied to the customer with delivery of hardware. Our acceptance test report will be prepared and kept on file at the contractor's facility.

TABLE A-III

AIR INDUCTION CONTROL AND ACTUATION SYSTEM OPERATION

Operating Conditions	Ramp System: Mode Switch Position	Ramp System: Ramp Operation	Bypass System: Mode Switch Position	Bypass System: Bypass Operation	Hydraulic Supply	Notes
Take-off & Carry	(Any)	--	(Any)	--	Off	1. Inlet Covers On 2. No Hydraulic Power
Prelaunch	1. Switch to "Auto"	--	1. Switch to "Auto"	--	1. Switch to "On"	1. Inlet Covers Off 2. Hydraulic System Energized
	2. "Auto"	a. Cycle to Start Inlet b. Hold Throat Param.	2. "Auto"	a. Modulate as required b. Closed Prior to Ignition c. Closed at Mininum Thrust	"On"	3. Fuel System Energized 4. Engine Nozzle Moves to Ignition Position 5. Engine Ignited Set For Minimum Thrust 6. Nozzle Released For Critical Control
	3. "Auto"	Modulating Near Fully Retracted Position	3. "Auto"	Opens as Required	"On"	7. Power Burst (Checkout)
Launch Acceleration Climb & Cruise	1. "Auto"	Extending Gradually with Speed	1. "Auto"	Closing Gradually from Wide Open With Speed	"On"	1. Engine Nozzle Wide Open Until Air Flow Match Mach Number is Reached
	2. "Auto"	- Same -	2. "Auto"	Normally Closed, Opens During Fast Transients	"On"	2. Engine Nozzle Starts Closing on Critical Control
	3. "Auto"	Near Maximum Extruded Position	3. "Auto"	-Same-	"On"	3. Engine Nozzle Near Minimum Area During Cruise On Critical Control

TABLE A-III (Continued)

Operating Conditions	Ramp System		Bypass System		Hydraulic Supply	Notes
	Mode Switch Position	Ramp Operation	Mode Switch Position	Bypass Operation		
Descent Power Off	1. "Auto"	Retracting With Speed	1. "Auto"	Closed Initially, Opens Gradually on Critical Control	"On"	1. Engine Shut-off 2. Engine Nozzle Locked In Closed Position 3. Pilot Switches to Override at Mach Number Below Which Variable Geometry Is No Longer Needed (Maximum Recovery For T/J)
	2. "Retract"	Hydraulic Locked In Retracted Position	2. "Close"	Hydraulic Locked In Closed Position	"On"	
Minimum Thrust	1. "Auto"	Slowly Retracting	1. "Auto"	Closed Except For Transients	"On"	1. Engine On Minimum Thrust 2. Nozzle On Critical Control
	2. "Retract"	Hydraulic Locked in Retracted Position	2. "Close"	Hydraulic Locked In Closed Position	"On"	1. Engine Shutoff 2. Nozzle Locked In Closed Position

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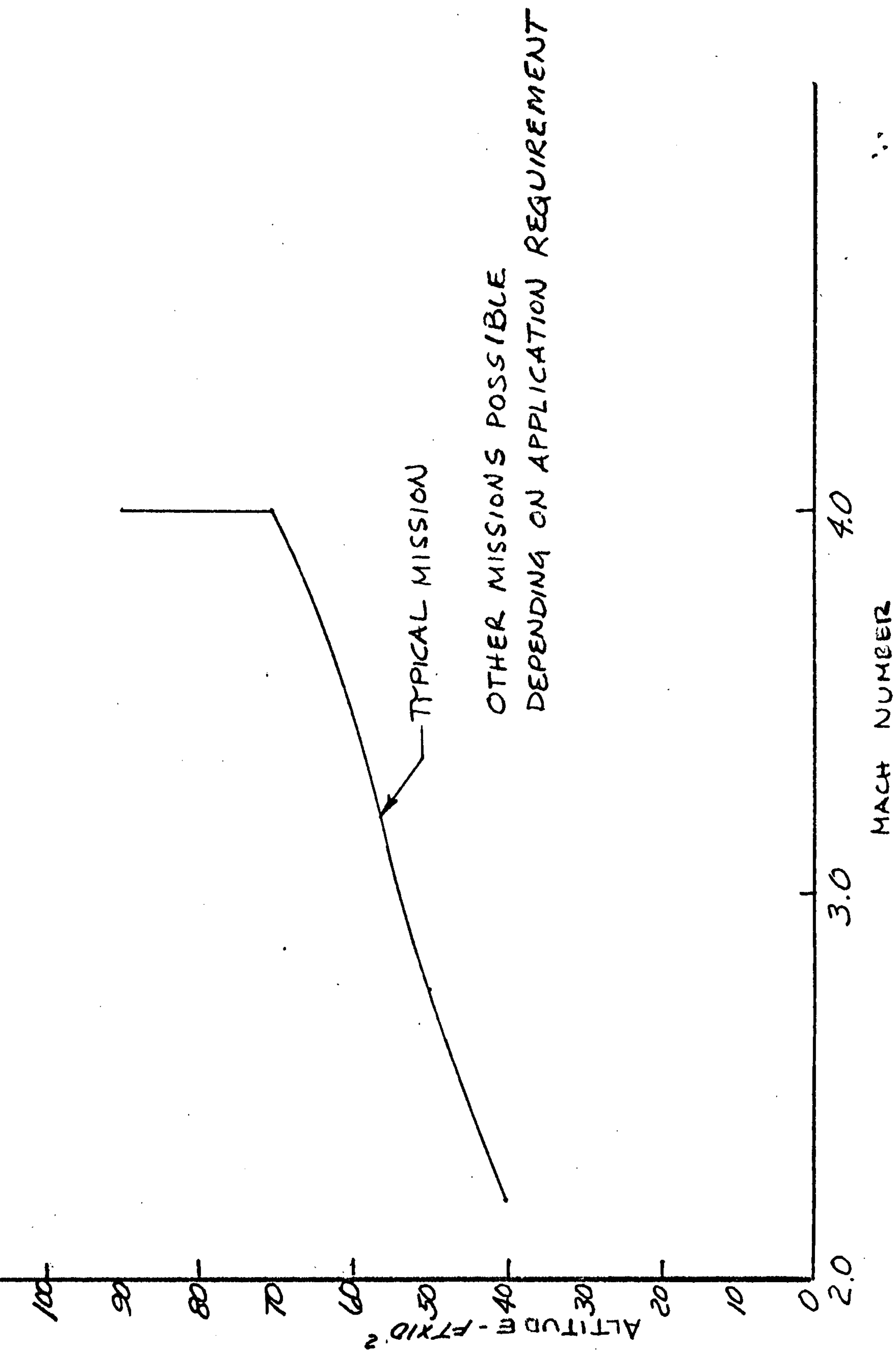
TYPICAL MISSION PROFILE



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CONTROL PARAMETERS *

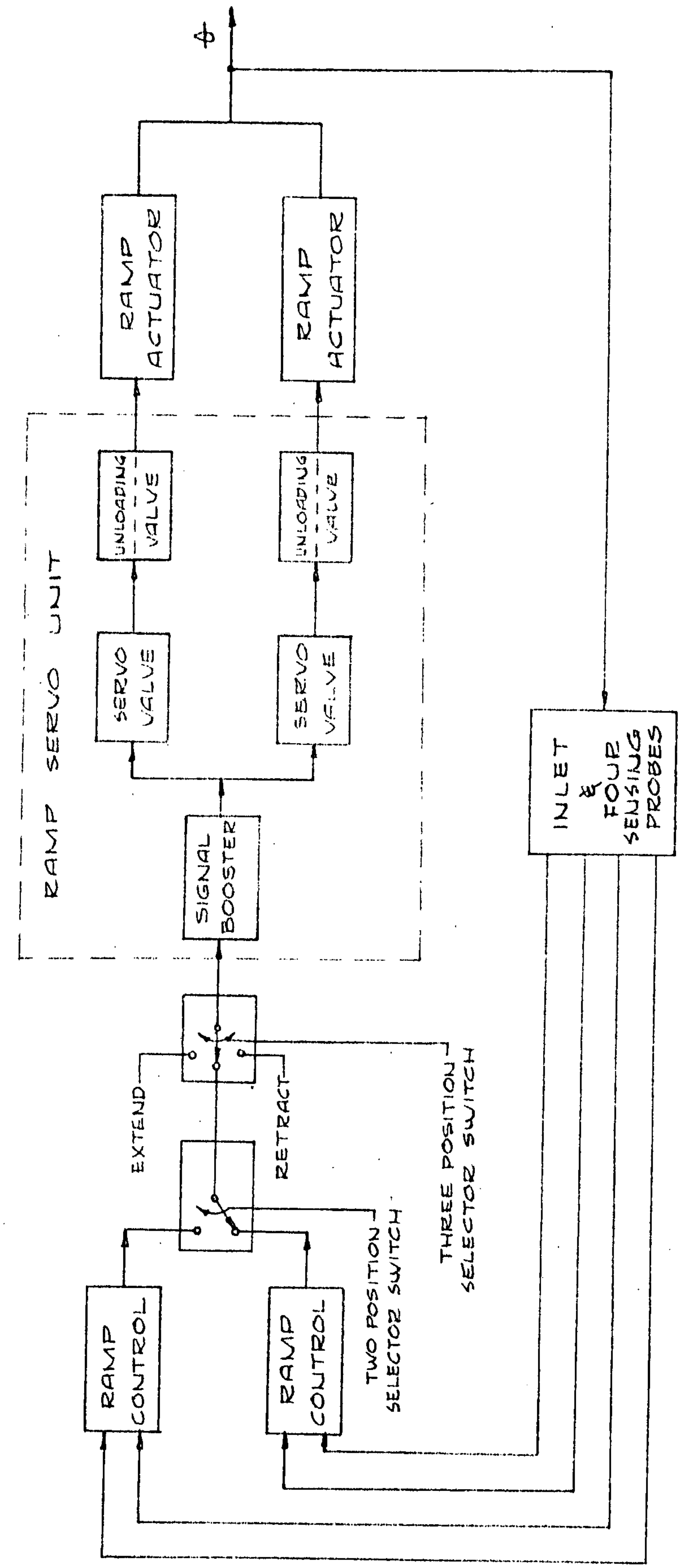
RAMP *

TO BE DETERMINED

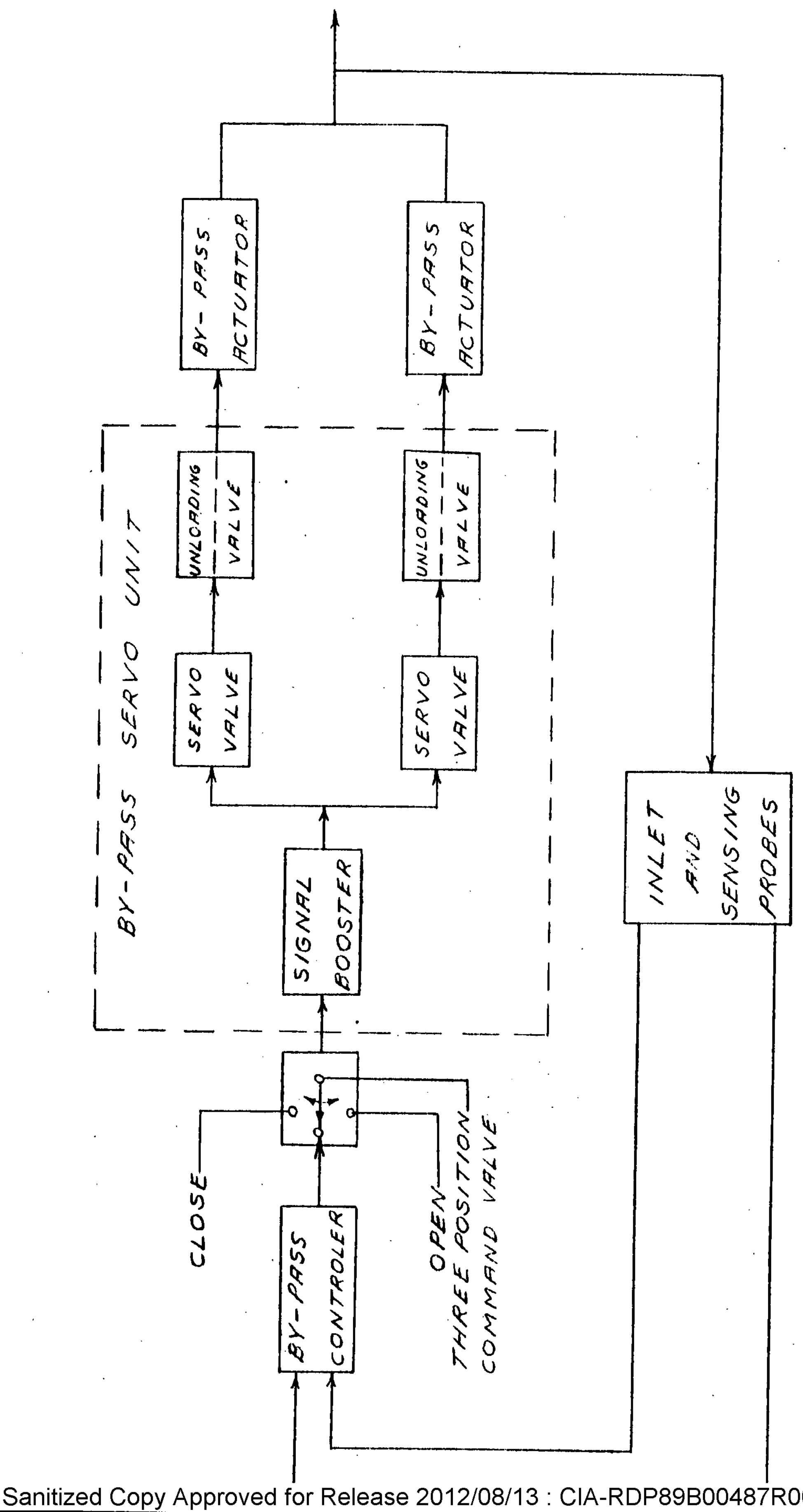
BY-PASS *

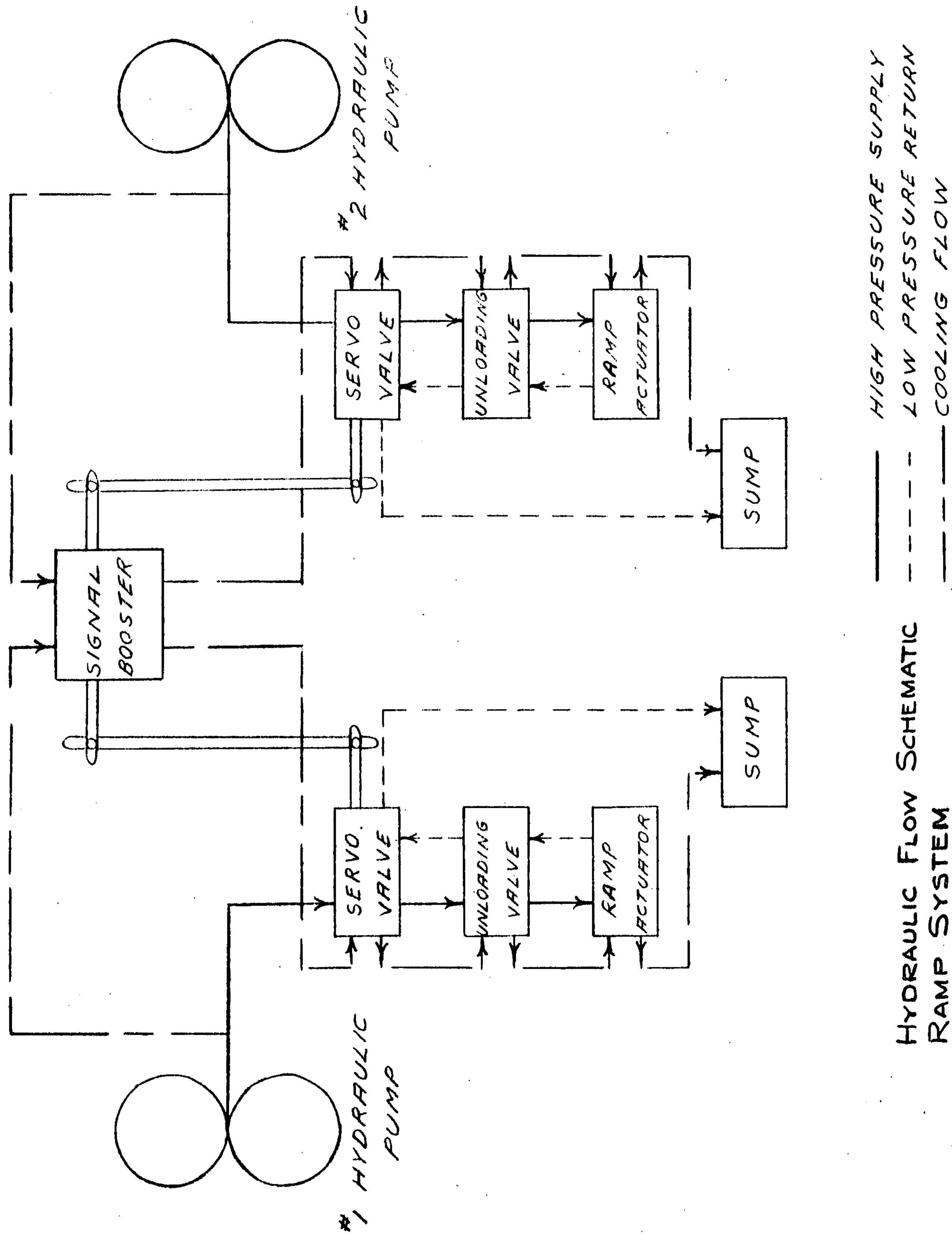
TO BE DETERMINED

BLOCK DIAGRAM~RAMP CONTROL SYSTEM

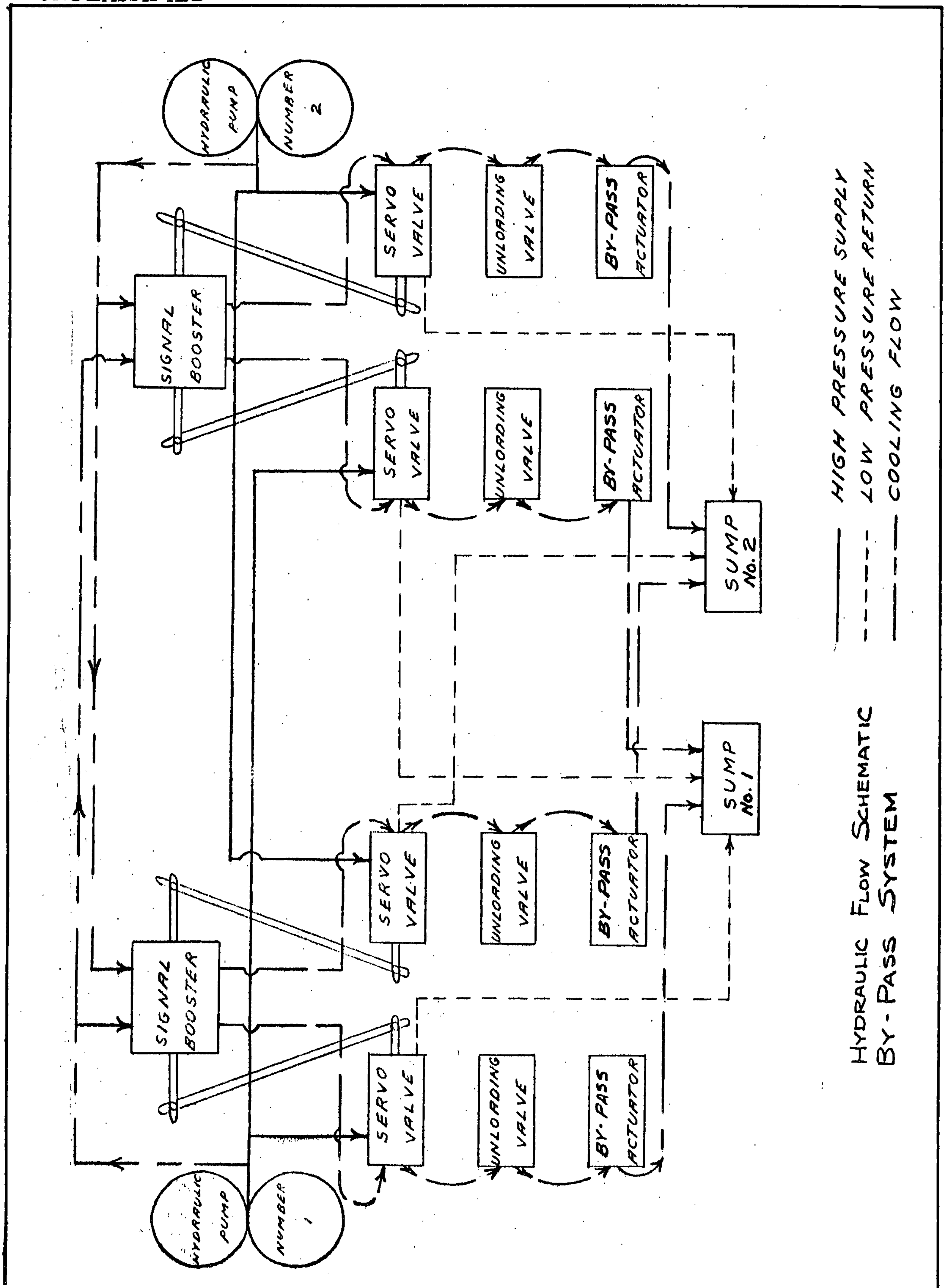


BLOCK DIAGRAM ~ BY-PASS CONTROL SYSTEM





HYDRAULIC FLOW SCHEMATIC
RAMP SYSTEM



HYDRAULIC FLOW SCHEMATIC
BY-PASS SYSTEM

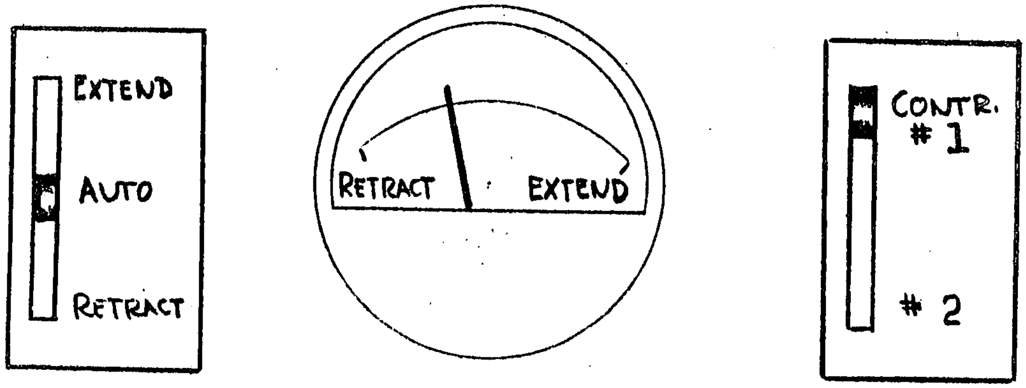
PROBE LOCATIONS *

TO BE DETERMINED

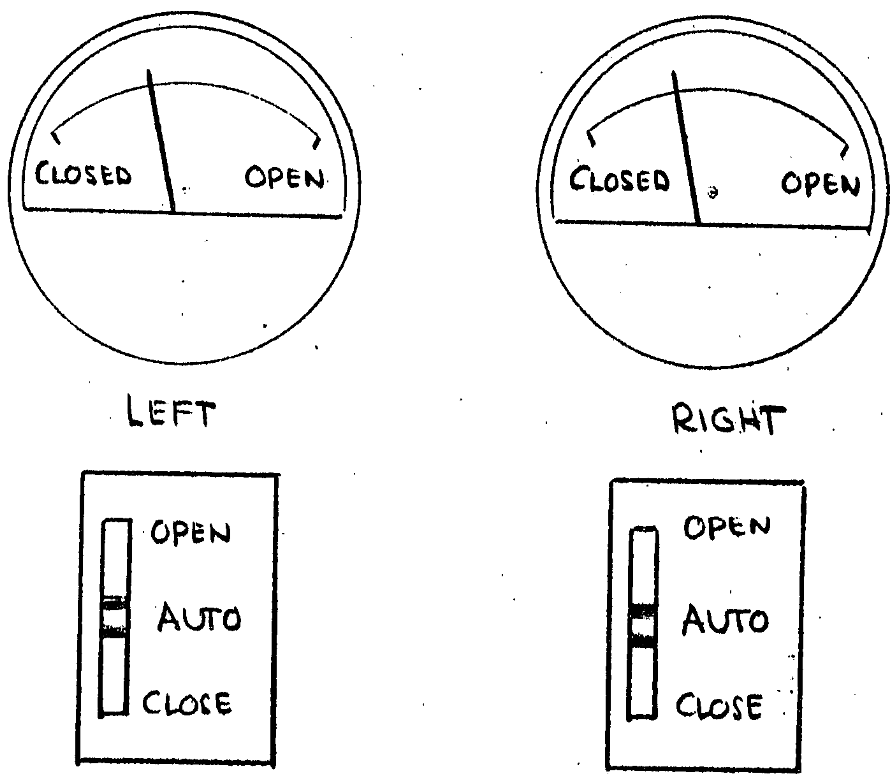
AC A673

TYPICAL PILOT PANEL

BYPASS SYSTEM



RAMP SYSTEM



SCHEMATIC OF PNEUMATIC TRANSMISSION LINES **

TO BE DETERMINED

AC A673

VIBRATION SPECTRUM

TO BE DETERMINED

SPACE ENVELOPES

RAMP AND BYPASS CONTROLLER **

TO BE DETERMINED

ELECTRICAL WIRING DIAGRAM **

TO BE DETERMINED

SPACE ENVELOPES

RAMP AND BYPASS SERVO UNIT **

TO BE DETERMINED

SPACE ENVELOPES

RAMP AND BYPASS ACTUATOR **

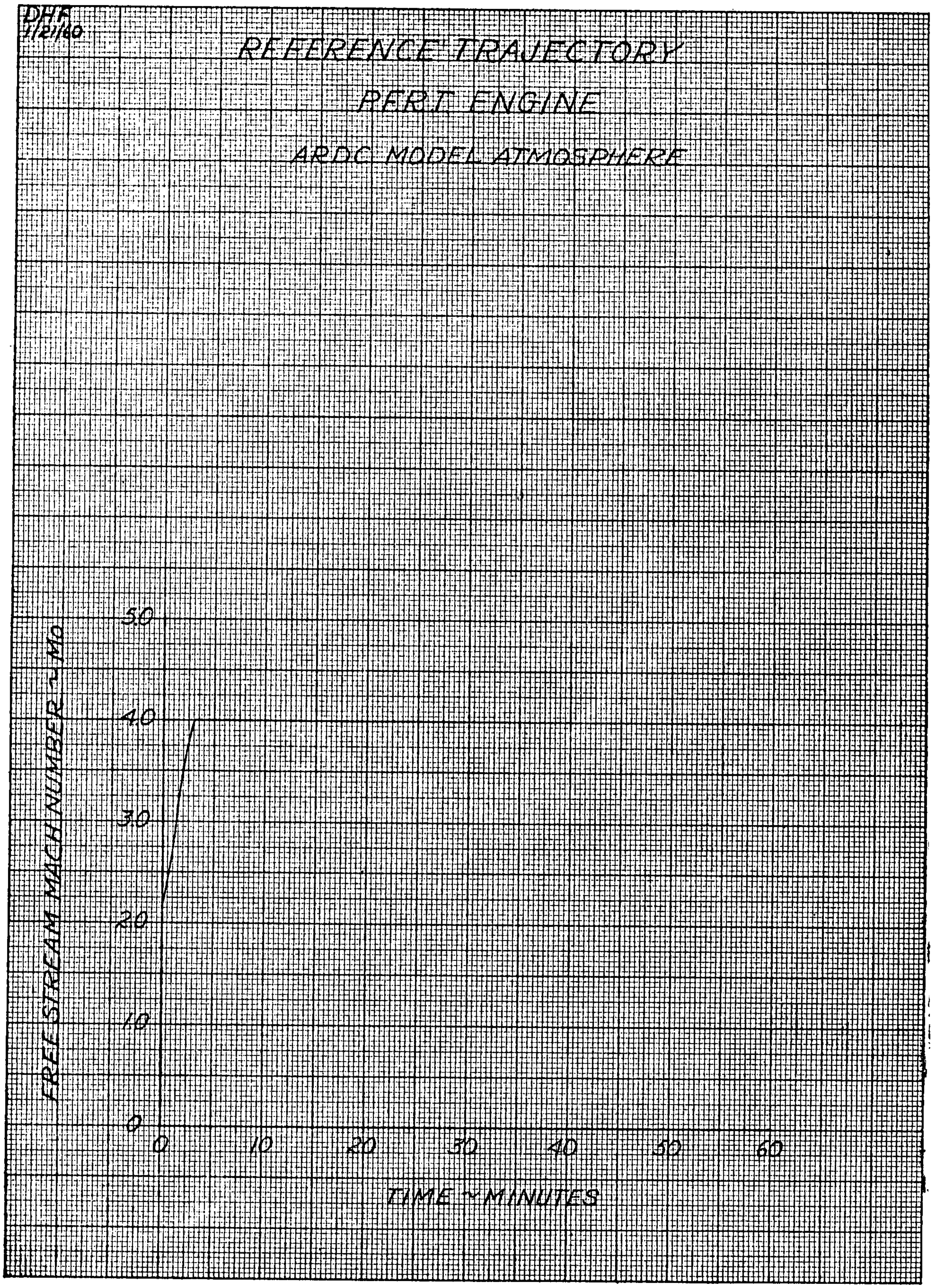
TO BE DETERMINED

PERFORMANCE OF BYPASS ACTUATOR

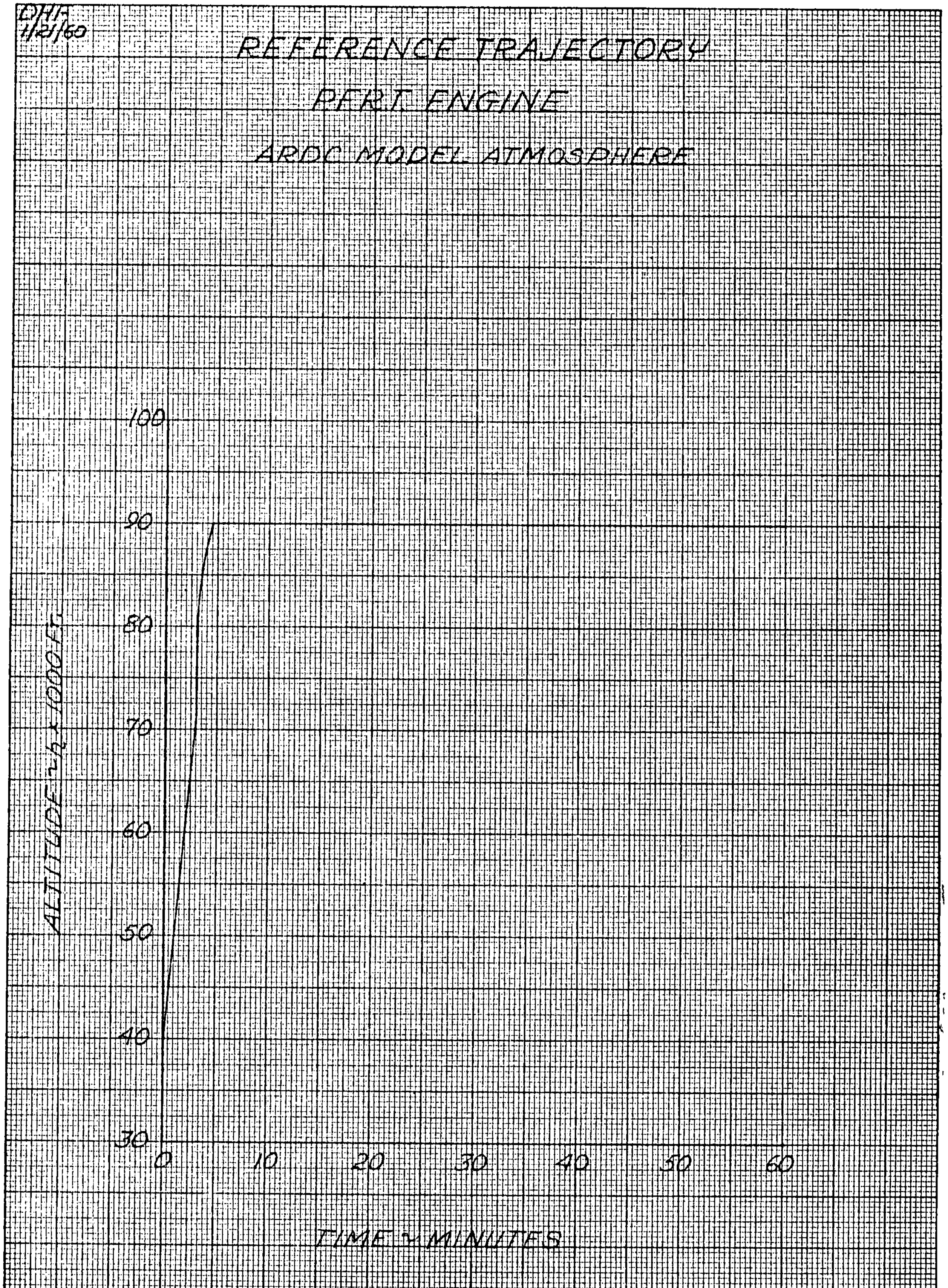
TO BE DETERMINED

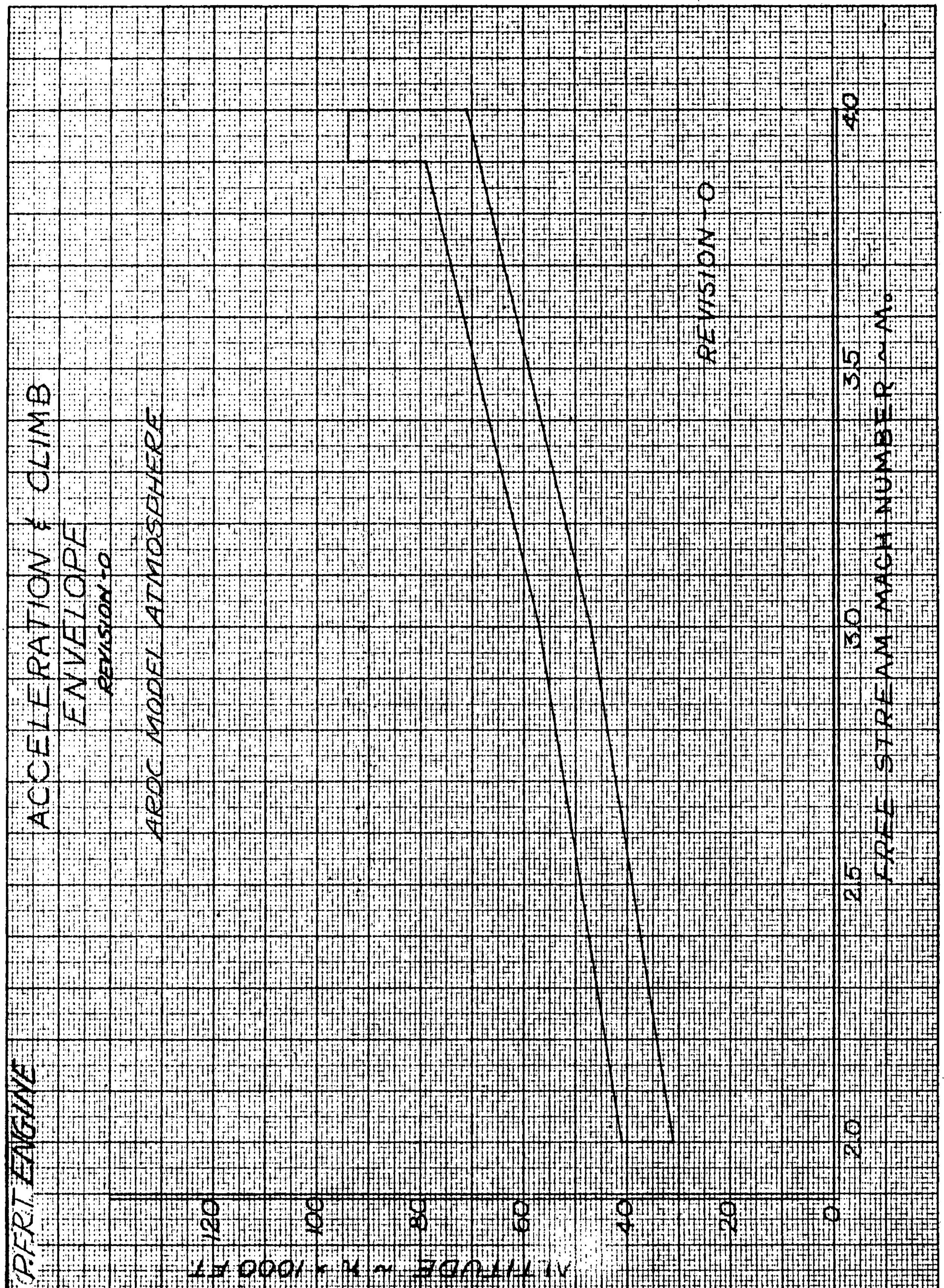
ADDENDUM I

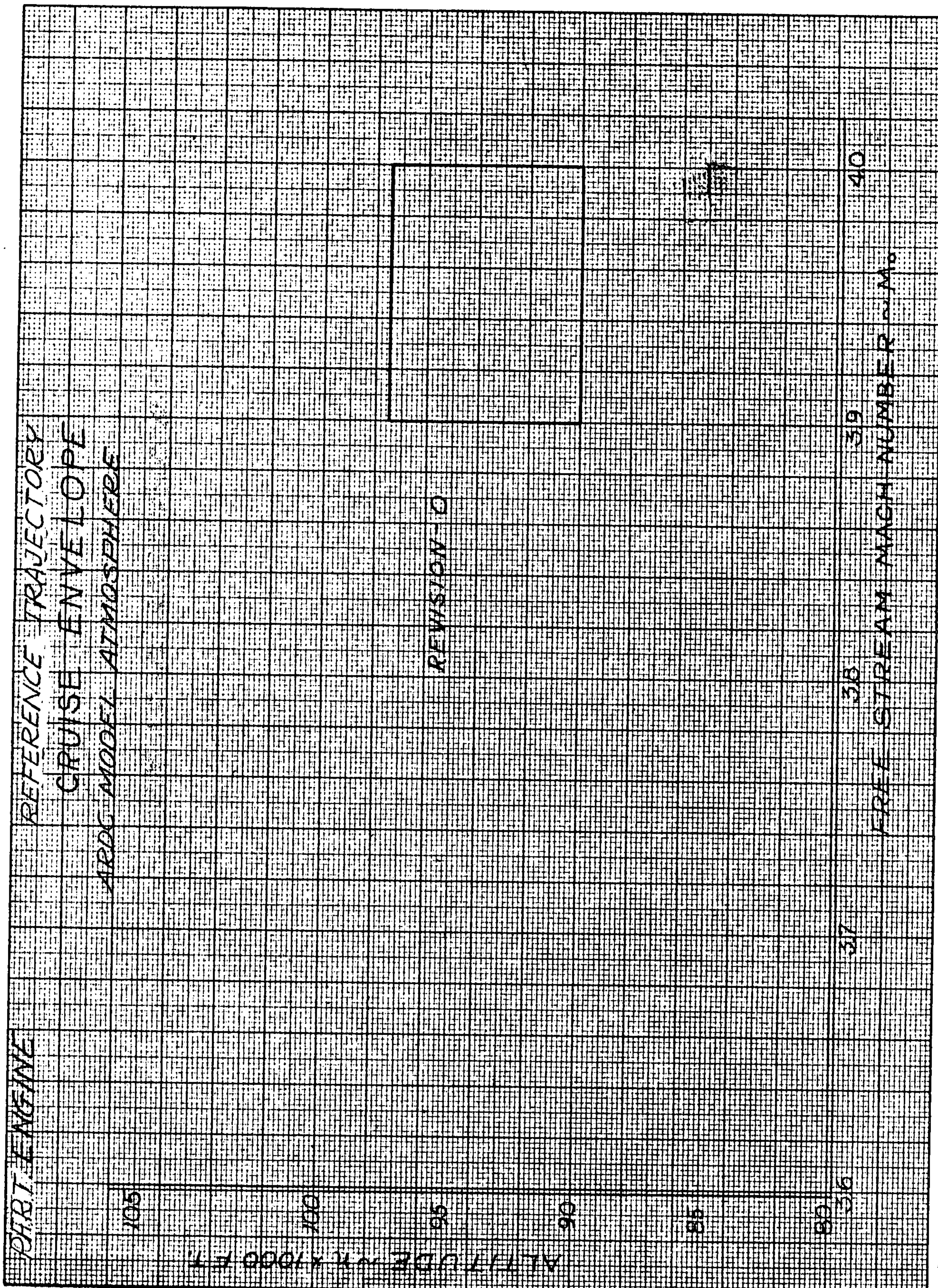
INTEGRATED ENGINE OPERATING LIMITS AND PERFORMANCE


DHF
1/21/60
REFERENCE TRAJECTORY
RERT ENGINE
ARDC MODEL ATMOSPHERE
FREE STREAM MACH NUMBER ~ Mo
50
40
30
20
10
0
0
10
20
30
40
50
60
TIME ~ MINUTES

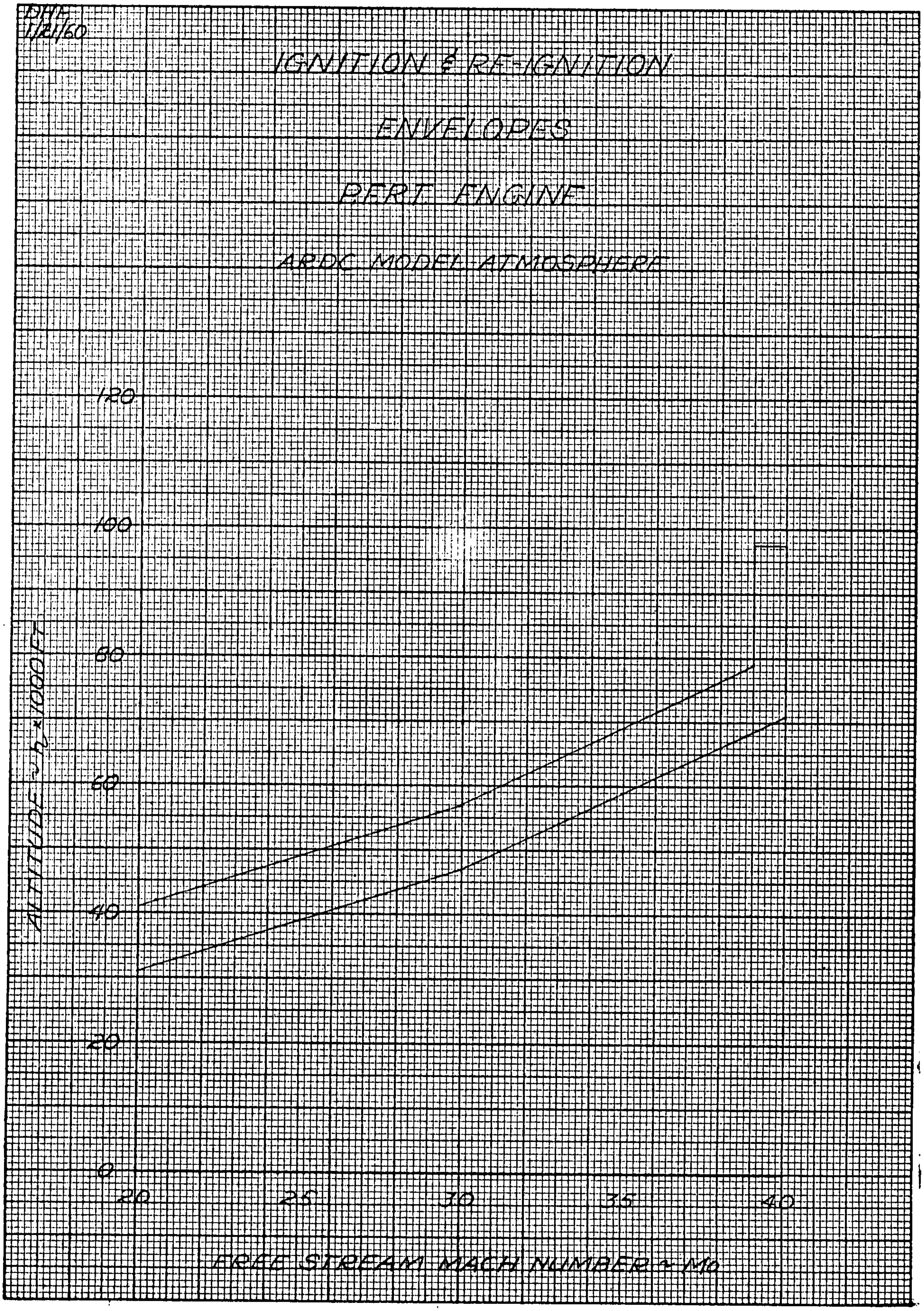
MAC A673

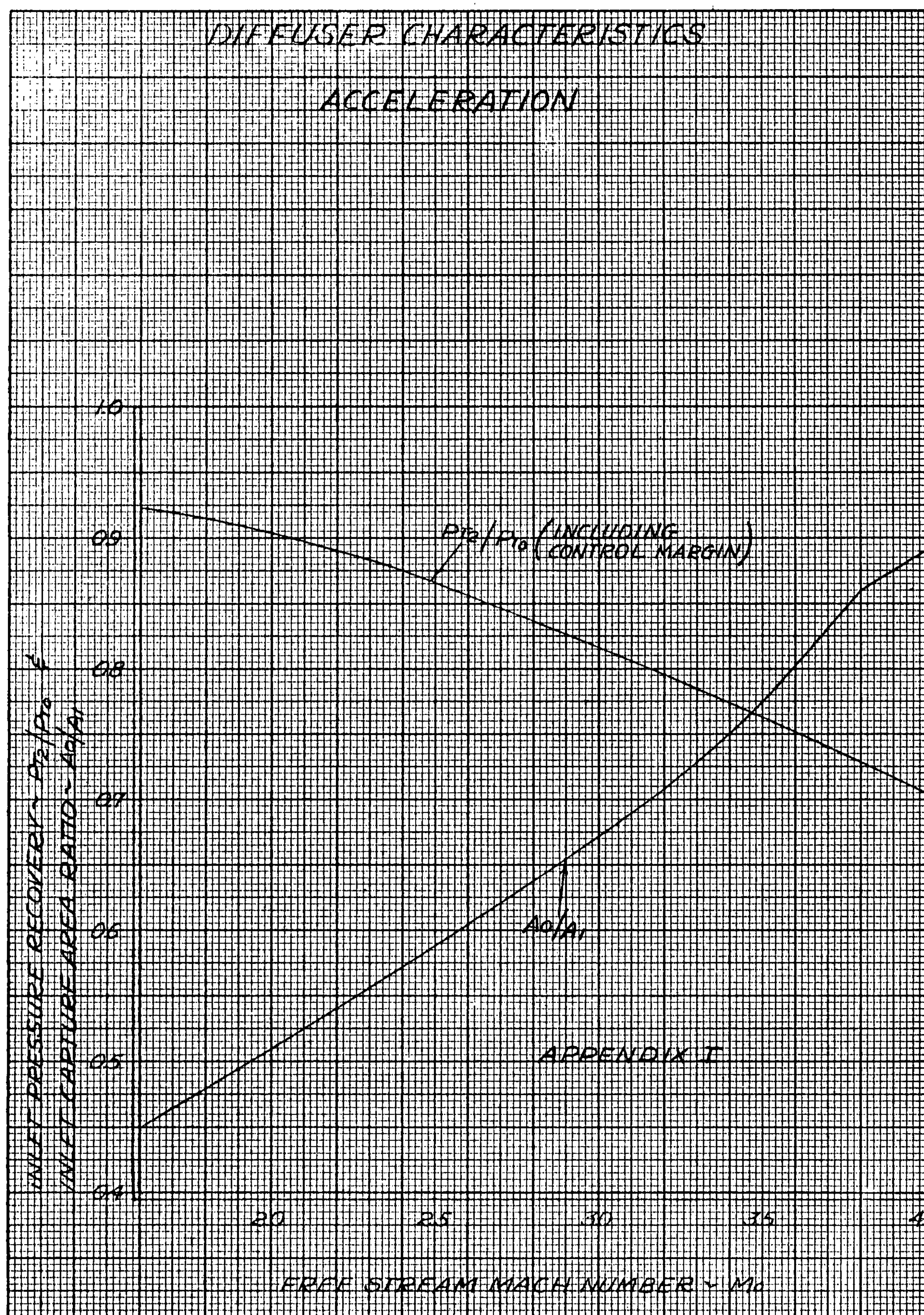

DHF
1/12/60
REFERENCE TRAJECTORY
PERT ENGINE
ARDC MODEL ATMOSPHERE
ALTITUDE ~ h x 1000 Ft.
100
90
80
70
60
50
40
30
0
10
20
30
40
50
60
TIME ~ MINUTES


PERF. ENGINE
ACCELERATION & CLIMB
ENVELOPE
REVISION-O
ARDC MODEL ATMOSPHERE
REVISION-O
2.0
2.5
3.0
3.5
4.0
FREE STREAM MACH NUMBER ~ M_0
0
20
40
60
80
100
120
ALTITUDE ~ H × 1000 FT


PHRT ENGINE
REFERENCE TRAJECTORY
CRUISE ENVELOPE
ARDC MODEL ATMOSPHERE
REVISION O
105
100
95
90
85
80
ALTITUDE ~ X 1000 FT
36
37
38
39
40
FREE STREAM MACH NUMBER ~ M_0

AC A673


DHL
1/21/60
IGNITION & RE-IGNITION
ENVELOPES
PERT ENGINE
ARDC MODEL ATMOSPHERE
ALTITUDE ~ h ×1000 FT
120
100
80
60
40
20
0
2.0
2.5
3.0
3.5
4.0
FREE STREAM MACH NUMBER ~ M₀


DIFFUSER CHARACTERISTICS
ACCELERATION
1.0
.09
.08
.07
.06
.05
.04
P_{T2}/P_{T0} (INCLUDING CONTROL MARGIN)
A_0/A_1
APPENDIX I
INLET PRESSURE RECOVERY ~ P_{T2}/P_{T0} &
INLET CAPTURE AREA RATIO ~ A_0/A_1
2.0
2.5
3.0
3.5
4.0
FREE STREAM MACH NUMBER ~ M_0

ADDENDUM II

ALTERNATE CONFIGURATION A

(Blunt Plug Nozzle)

INTRODUCTION

This configuration conforms to Revision 2 of the "PFRT Engine Model Specification Including Air Induction Control and Actuation System" with the following deviations:

Section I. Engine Model Specification

2. Installation Features

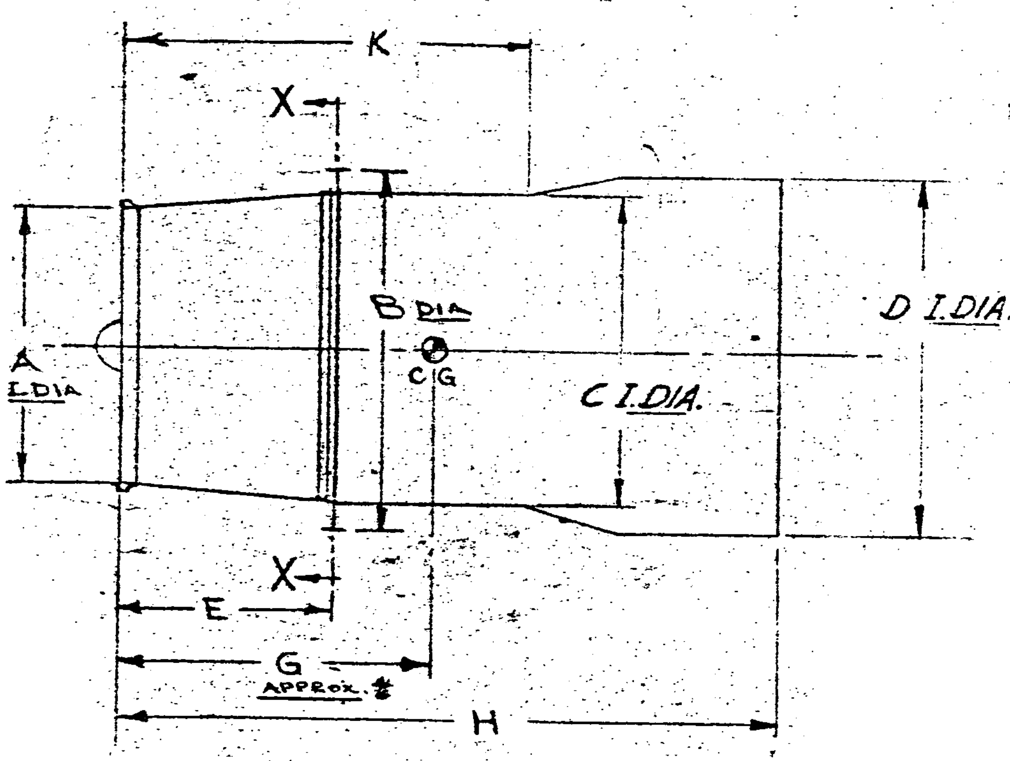
2.1. Dimensions.- An installation drawing of the engine is shown in Figure A-58. The dimensions are noted for 70°F and also at maximum operating temperature. Detailed engine drawings shall be provided the airframe contractor as they become available.

2.2. Weight.- The dry weight of the complete engine excluding instrumentation and excluding control intelligence pressure lines forward of the engine inlet shall not exceed 880 pounds. This weight also excludes any exterior shrouds and attachments thereto for ducting diffuser bleed air aft, and excluding the weight of any insulation which may be required between the engine and the airframe.

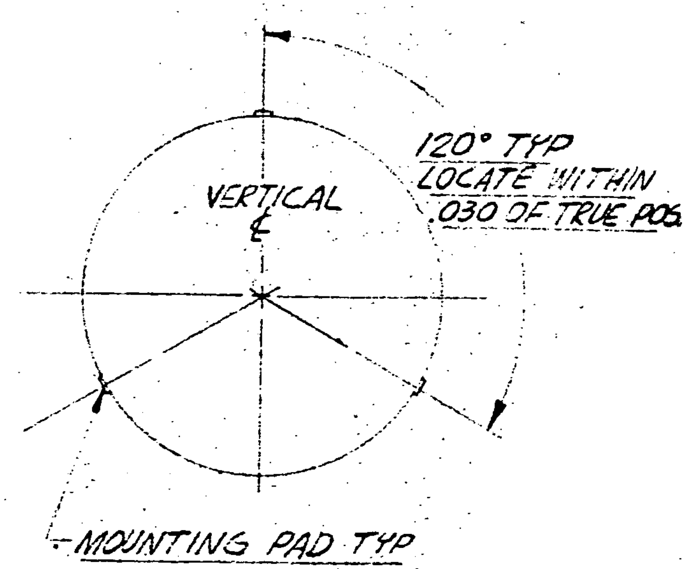
3. Performance Characteristics

3.2. The ratings and curves shown in Figures ___ through ___ of Revision 2 of the "PFRT Model Specification Including Air Induction Control and Actuation System" shall be adjusted by the thrust correction factor shown in Figure A-59.

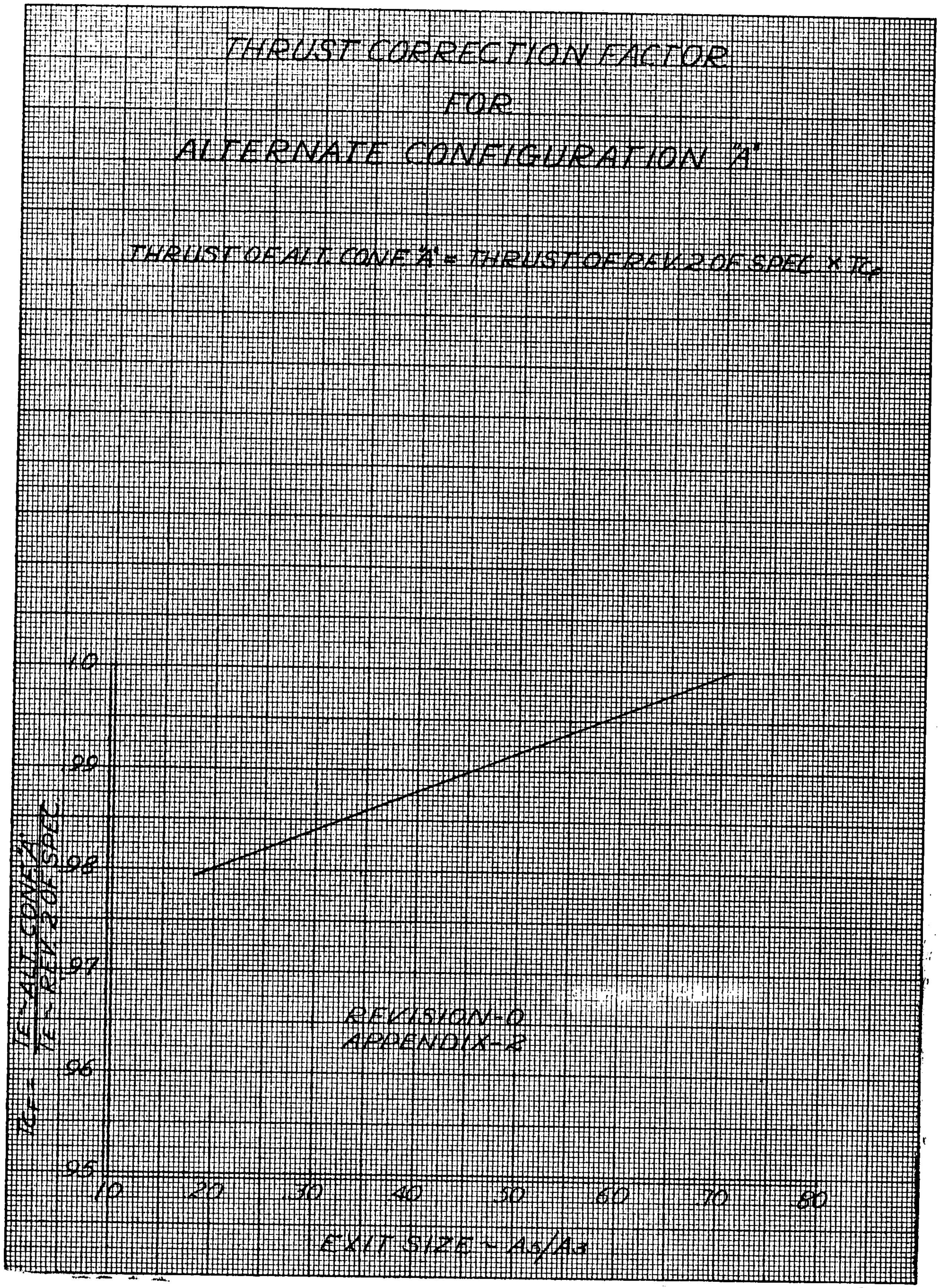
ENGINE INSTALLATION DRAWING



DIM.	COLD	HOT	
A	33.000	33.290	DIA'S
B	40.321	40.740	
C	37.713	38.141	
D	40.976	41.500	
E	24.262	24.500	LENGTH
* G		35.0	
H	75.676	76.520	
K	46.830	47.301	



SECTION X-X


THRUST CORRECTION FACTOR
FOR
ALTERNATE CONFIGURATION "A"
THRUST OF ALT. CONF. "A" = THRUST OF REV. 2 OF SPEC × TCF
TCF = TF - ALT. CONF "A" / TF - REV. 2 OF SPEC
1.0
.99
.98
.97
.96
.95
10
20
30
40
50
60
70
80
EXIT SIZE ~ A5/A3
REVISION-0
APPENDIX-2